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ABSTRACT

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Cognitive difficulties are frequently documented in clinical Attention Deficit Hyperactivity Disorder (ADHD) samples. Whether these cognitive weaknesses are associated with ADHD symptoms in non-clinical samples is unknown. The current study examined the relationship between ADHD symptoms and cognitive performance in a non-clinical adult sample of 75 men and women (ages 20 to 49). Self-report measures of ADHD symptoms and neuropsychological assessments examining sustained attention, inhibition, impulsivity, and working memory were administered. Results revealed that: (1) individuals with high total ADHD scores had a difficulty in sustaining attention on a repeated trial task; (2) hyperactive/impulsive scores had a significant positive correlation with impulsivity but not with disinhibition; (3) inattentive scores had a negative trend correlation only with a simple auditory/verbal working memory task. The present study revealed that even the individuals with sub-clinical ADHD symptoms had similar difficulties associated with sustained attention, impulsivity, and simple verbal working memory in neurocognitive tests.

Neurocognitive Features of Attention Deficit Hyperactivity Disorder

in a Non-clinical Adult Sample

by

Su-Jong Kim

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1. Introduction

Cognitive performance can be measured using neuropsychological assessment tools. These neuropsychological tools assess specific cognitive functions, including attention, memory, use of knowledge, language, learning, reasoning, and problem solving. Information about these specific aspects of cognition can be used to make predictions about behavior or performance in specific situations.

Attentional functions are a widely studied aspect of cognitive performance. A large volume of literature is devoted to attentional disorders among individuals with clinical Attention Deficit Hyperactivity Disorder (ADHD). These studies have yielded important information about the connections between specific brain regions and the cognitive performances related to ADHD. Specifically, it has been reported that individuals with ADHD have executive function deficits, which have been associated with dysregulation of prefrontal lobe region.

Individuals diagnosed with ADHD commonly demonstrate impulsive responding, and difficulties with inhibition, working memory, and sustained attention on neurocognitive measures. However, the extent to which these neurocognitive features of ADHD are present in a non-clinical sample has not been thoroughly investigated. It is possible that similar cognitive difficulties in sub-clinical ADHD people exist and these may also negatively impact daily functioning and performance. Therefore, the present study examined the relationship between cognitive performance and reported symptoms of ADHD in a non-clinical sample of adults.

As background for the current study, the following sections provide a brief discussion of cognitive neuropsychology, measurement methods of cognitive performance, and individual variability in cognitive performance. Clinical studies of ADHD are reviewed next including the neuropsychological weaknesses under investigation in the current study. The introduction section concludes with the rationale and hypotheses of the current study. The remainder of the theses describes the methods, results, and provides a discussion of the cognitive characteristics of individuals with sub-clinical ADHD.

1.1. Cognitive Neuropsychology

Cognitive neuropsychology represents a blend of cognitive psychology and neuropsychology emphasizing the relationship between brain functioning and information processing in non-clinical populations. Cognitive psychology uses the framework of the human as "information processor," in which cognition is defined as information processing. Cognitive psychologists try to understand individual differences in cognitive performance based on general theories of how the normal functioning brain works and how individuals process information from the perception of information to the production of behavior (Medin & Ross, 1996).

Neuropsychology, unlike cognitive psychology, is an applied science historically concerned with the cognitive and behavioral impact of cerebral damage. Localization of brain injury and development of treatment programs for improving disrupted functioning have been the central focus (Lezak, 1995). Effects of specific brain injuries on the "higher" (cortical) cognitive functions, such as memory, language, perception, and attention as well as on the emotional and physical functions are common areas of assessment (Andrewes, 2001). Therefore, most traditional neuropsychological assessment tools have been developed for the assessment of cognitive function among individuals with cerebral defects (Andrewes, 2001). In sum, traditional neuropsychology has had a major focus on clinical samples with specific problems including brain-injury and neurological disorders. It has been argued that traditional neuropsychological tools have limited applications to non-brain injury populations (Lezak, 1995).

Although cognitive psychology and neuropsychology have used different methods to understand cognition, recently these disciplines have been integrated as a specialized field, cognitive neuropsychology (Andrewes, 2001). Incorporating cognitive psychology into existing traditional neuropsychology, cognitive neuropsychologists started to examine cognitive processes that occur across different stages of task completion, rather than strictly emphasizing discrete, task-defined abilities, and localization of function (Feinberg & Farah, 2003). Briefly stated, cognitive neuropsychology examines the relationship of the structural and functional aspects of the brain with cognitive processing, using neuropsychological assessment measures primarily in individuals without documented structural or functional brain abnormalities.

1.2. Neurocognitive Assessments

Human cognition is comprised of different domains of functioning (e.g., attention, memory, problem solving). In the field of cognitive neuropsychology, these specific domains of functioning and performance are assessed using a variety of cognitive tasks. Performance on these tasks can be used to evaluate specific cognitive functions and to make inferences about possible areas of brain dysfunction. Further, neurocognitive assessments can isolate specific aspects of cognition and provide investigators with information about the relationship between performance and specific brain regions. The tools used today are based on traditional neuropsychological assessment methods for evaluating specific functional domains, and newer processing-oriented procedures that have been made available with contemporary computer-based technology.

Traditional neuropsychological assessment methods include paper-pencil, hands-on, and question-answer tasks. An examiner administers every task to each individual. Potential advantages of using such traditional measures include the following: (1) traditional assessments are useful to gather a complete picture of a person when given in a long comprehensive battery format, (2) traditional assessments provide additional information that can be helpful for interpretation of results (e.g., an examinee's body language and behavioral presentation), and (3) these assessments have long traditions in usage, and they tend to have well-established validity. The disadvantages of using traditional assessment batteries include the time consuming nature of comprehensive neuropsychological assessments and, therefore, it is physically and mentally exhausting for participants and examiners. More importantly, traditional assessments are prone to learning effects (practice effects), and may be insensitive to subtle changes in performances over time. Similarly, because traditional assessments do not yield precise processing speed in general, subtle differences among individuals may not be detectable (Wilken et al., 2003).

Computerized assessments offer another way to measure cognition. In general, computerized assessment tools are used in conjunction with traditional neuropsychological assessment tasks to complement weaknesses of traditional assessments. For example, computerized tests such as the Spaceflight Cognitive Assessment Tools battery (S-CAT; Reeves et al., 1992) allow recording of reaction times, accuracy, and performance efficiency (Kabat, Kane, Jefferson, & DiPino, 2001).

Computers can provide data on the precise times between the presentation of stimuli and individuals' responses in the unit of milliseconds, enabling information regarding speed and efficiency of cognitive processing. Additionally, because of the degree of precision available from the data, more subtle differences can be detected (e.g., performance changes over time, across conditions, or individuals). Another distinct advantage of using computerized assessment tools is that the tasks are easier to administer and less time consuming. However, computerized assessment alone does not provide a full description of an individual's cognitive status because of the restrictions in the types of tasks that can be performed on a computer. Therefore, computerized tasks may complement traditional neurocognitive assessments by allowing examination of subtle differences in information processing associated with simple and choice reaction times (Kay et al., 1997; Starbuck, Bleiberg, & Kay, 1995).

1.3. Individual Variability in Cognitive Performance

Traditional and computerized neurocognitive assessment tools are used to examine human cognitions in two different ways: inter-individual variability and intra-individual variability. Intra-individual variability refers to the performance variability in different domains of cognition within a single individual (i.e., strengths and weaknesses), and inter-individual variability entails differences in performances between people. Comprehensive neurocognitive tasks measure performances across different cognitive domains, and have revealed that people, in general, do not have the same level of performances across different cognitive domains (Schretlen, Munro, Anthony, & Pearlson, 2003). Schretlen and colleagues (2003) reported, in examining 197 samples, participants do not have a consistent relative level of performance across all cognitive tests, and everyone has weaknesses and strengths of cognitive performances.

Although intra-individual variability occurs as natural phenomenon in cognition, neuropsychology has historically focused on diagnosing cerebral dysfunction based on examination and identification of a brain-injured group in comparison to a non brain-injured group. The “normative” group is assumed to represent the mean for each domain, and deviation observed in the brain-injury patient’s performance across different domains was believed to reflect the effects of the injury (Schretlen et al., 2003).

In addition to distinct differences between clinical and non-clinical samples, more subtle differences in cognitive performances among individuals without clinically diagnosable neurological disorders or brain injuries can also be detected using neuropsychological measures. For instance, in a study investigating a psychiatrically normal sample, the level of social anxiety (discomfort in social contexts) was related to performances specifically on executive functioning tasks, such that higher anxiety related to poorer performance on the Stroop interference trial and the Trails B task but not with simple Stroop and Trials A (Ashburn, 2002).

Similarly, among individuals without clinically diagnosable attention deficit disorders, people with high scores on attentional problems might have certain cognitive difficulties that are associated with attention. Although these cognitive differences in a non-clinical adult sample may not be as distinct as in clinical ADHD samples, the cognitive difficulties may, nonetheless, exist and may be detected using neurocognitive assessment tools.

1.4. Attention Deficit Hyperactive Disorder as an Individual Differences in Attentional Features

ADHD is a neurobehavioral disorder that is characterized by inattention, impulsivity, and hyperactivity (Diagnostic and Statistical Manual of Mental Disorders, 4th Edition [DSM-IV], APA, 1994). The DSM-IV identifies three subtypes of disorders of attention; ADHD/Primarily Inattentive Type, ADHD/Primarily Hyperactive-Impulsive Type, or ADHD/Combined Type, depending on the mix of inattention, impulsive or hyperactive symptoms, respectively (APA, 1994). Although ADHD was initially thought of as a childhood disorder that becomes negligible or attenuates with age, Barkley (1998) estimated that 50 –70% of ADHD diagnosed children continue to exhibit ADHD symptoms as adults. Consistent with this estimate, a longitudinal study of boys with ADHD revealed that at age 19, 38% had symptoms that met full criteria for an ADHD diagnosis, 72% had persistence of at least one third of the symptoms required for the diagnosis, and 90% had clinically significant impairment later in life (Biederman, Mick, & Faraone, 2000).

The ADHD/Primarily Inattentive type is defined as meeting six of nine behavioral symptoms of inattention. The ADHD/Primarily Hyperactive-Impulsive type is defined as meeting six of nine hyperactive/inattention symptoms. The Combined type is meeting both inattentive and hyperactive criteria (six out of nine for both sets of symptoms). These are the clinical diagnoses defined by DSM-IV criteria; however, the dichotomous diagnosis of adults with ADHD has been criticized as a shortcoming of the DSM system (Krueger & Piasecki, 2002).

1.4.1. Criticisms of DSM-IV diagnosis of ADHD and attention on a continuum

The DSM-IV diagnostic criteria for ADHD were developed for evaluating children and, therefore, are age-limited in the nature of many of the criterion symptoms (Wender, Wolf, & Wasserstein, 2001). Hill and Shoener (1996) and Murphy and Barkley (1996a) reported a gradual systematic decrease in ADHD prevalence with age when following the strict DSM-IV criteria for diagnosis. Hill and Shoener (1996) dismissed adulthood ADHD because of the extremely small prevalence among adults over 40 years old when based on the formal diagnostic criteria. The authors argued that ADHD is a childhood disorder that disappears with age. However, unlike Hill and Shoener (1996), Murphy and Barkley (1996a) reported that the apparent decreased rate of adult ADHD was because the ADHD threshold for diagnosing children is more stringent and harder for adult ADHD patients to meet. The authors argued that a gradual decrease in the prevalence of ADHD with age is the result of the differences in the childhood and adulthood ADHD symptoms rather than an actual reduction in the difficulties associated with ADHD symptoms.

A variety of studies of adult ADHD have reported findings supporting Murphy and Barkley's (1996a) claim. Barkley's (1998) study stated that while childhood ADHD is characterized by more overt behavioral manifestations of attentional difficulty involving hyperactivity, adult ADHD is characterized by cognitive inefficiency primarily associated with inattention and impulsive responding. Similarly, it has been noted that hyperactive symptoms diminish at a greater rate than inattentive symptoms, and that subtler executive dysfunctions associated with the disorder can emerge in adults (Biederman et al., 2000; Wolf & Wasserstein, 2001). According to Wilens, Biederman, and Spencer (2002), the report of problems related to simple over-activity declines among adult ADHD patients. The most notable residual symptoms of ADHD in adulthood are the persistence of restlessness and poor concentration, with one third of whom complaining of significant cognitive problems, such as inability to concentrate, forgetfulness, and confusion. In addition, problems with self-regulation (e.g., lack of organization, inability to establish and maintain a routine, poor discipline) were the most frequently reported symptoms among adults (Wolf & Wasserstein, 2001). This change in symptom manifestation associated with ADHD from overt behavioral problems in childhood to more subtle cognitive problems in adulthood suggests that the DSM-IV criteria for diagnosing ADHD are not developmentally sensitive to detect ADHD in adults (Faraone, Biederman, Feighner, & Monuteaux, 2000).

In response to these issues, some investigations (e.g., Bradley & Golden, 2001; Faraone, Biederman, Feighner et al., 2000; Murphy & Barkley, 1998) have suggested alternative conceptualizations to diagnose ADHD. One approach is to adopt a norm-referenced rather than a criterion-referenced diagnostic system for adults. This means that based on a normal distribution of ADHD symptoms in a general adult population, cutoff points should be created for diagnosing adulthood ADHD (e.g., top 7 percent, 1.5 SD above the mean) (Murphy & Barkley, 1998). Similarly, Bradley and Golden (2001) have questioned the idea of a dichotomous diagnosis of ADHD and have instead characterized ADHD as the extreme end of an attention ability continuum. According to these researchers, the dichotomous diagnosis of ADHD reflects an arbitrary cutoff that leads to conflicting findings in studies of ADHD. These authors suggest that an alternative approach classifying ADHD along a continuum of symptom severity might be more appropriate to identify and understand the functional impact of ADHD.

1.4.2. Neurological evidence associated with ADHD

Even though the purpose of the current study was to examine non-clinical adult samples, comparison data used to identify attentional features, underlying neuroanatomical differences, and cognitive performances is based on studies of clinical ADHD samples, and the brain-injured populations. Specifically, individuals who suffer lesions to the frontal lobes exhibit impulsive behavior, lack of inhibition, and inattention. Because these characteristics are the hallmark of ADHD, ADHD is believed to result from disruptions in the frontal lobe circuitry of the brain (Bradley & Golden, 2001). Research on the role of frontal lobe functions and the associated neural network systems in clinical ADHD samples have led to observations consistent with the findings of structural and functional brain abnormalities in individuals with ADHD. For instance, overall brain size and the superior prefrontal area are reported to be smaller in ADHD patients compared to the non-ADHD controls (Hill et al., 2003).

Other investigations focused more on the functions rather than anatomical features to understand ADHD. For example, ADHD was associated with reduced activity in frontal brain regions, and the cognitive and behavioral difficulties were related to extent of hypofrontality. Additional support for the hypofrontality hypothesis has been provided by neuroimaging studies (Ernst et al., 1994; Giedd, Blumenthal, Molloy, & Castellanos, 2001; Lou, Hendrickson, Bruhn, Borner, & Nielsen, 1989; Zametkin et al., 1993) and pharmacological interventions (Castellanos et al., 1996; Levy & Swanson, 2001).

In addition to the role of the frontal lobes in ADHD, specific right lateralized neuroanatomical and neurochemical pathways have been found to be closely involved in the specific symptoms of ADHD (Stefanatos & Wasserstein, 2001). These findings suggest more intricate involvement of different parts of the brain in ADHD than initially postulated. Related to this point, heterogeneous expressions of ADHD have been documented, which further complicates the neurocognitive investigations of the disorder. Because there is involvement of different parts of the brain and individual differences in cognitive profiles (weaknesses and strengths), the cognitive symptom manifestation would be inevitably heterogeneous.

To date, the precise neural and pathophysiological substrate(s) of ADHD remain incompletely understood. However, based on the most common cognitive difficulties observed in people with ADHD, the prefrontal region has been the main focus of cognitive neuropsychological research in ADHD.

1.4.3. Cognitive weaknesses and purported specific brain regions associated with ADHD from clinical studies

Cognitive weaknesses relating to attention and frontal/executive functions are frequently reported in ADHD (Woods, Lovejoy, & Ball, 2002). Executive functions reflect a multidimensional neurocognitive construct comprised of various higher order processes such as attention, concept formation, problem solving, planning, impulsivity and inhibition, and cognitive flexibility (Spreen & Strauss, 1998). These symptoms are similar to the deficits observed following damage to the frontal lobe. Therefore, individuals with ADHD are believed to have poorly functioning or under-aroused frontal lobes. However, not all individuals with ADHD experience all of the symptoms, and individuals with ADHD vary in their performance as measured by neuropsychological testing. These differences call into question the diagnosis of ADHD as a unified construct.

The specific cognitive profiles associated with Attention Deficit Hyperactivity Disorders have varied across studies. For example, some investigators describe ADHD as weaknesses in selective visual attention and/or prepotent response disinhibition as measured by the Stroop color-naming test (Lovejoy et al., 1999; Murphy, Barkley, & Bush, 2001). Other investigators report that individuals with ADHD exhibit poor working memory performance as measured by the Trail Making Test and the Digit Span Test (Barkley, Murphy, & Kwasnik, 1996; Holdnack et al., 1995; Woods, Lovejoy, & Ball, 2002). Still others report no differences in working memory or visual attention, but deficits in other areas. Kovner and colleagues (1998), for example, report that adult ADHD patients have deficits in reversing, shifting, inhibiting and re-engaging specific cognitive and motor sets without difficulties in short-term memory, working memory, and sustained attention. These findings suggest that ADHD may not be a unitary construct or that investigators use different criteria for defining ADHD.

The arbitrary cutoff of reported symptoms for diagnosing ADHD based on the DSM-IV criteria or other ADHD questionnaires may contribute to conflicting findings between different ADHD studies. That is, different studies may have employed different operational definitions for ADHD. Moreover, the inconsistencies in the literature may arise from combining the three distinctive subtypes of ADHD (ADHD/Primarily Inattentive type, ADHD/Primarily Hyperactive/impulsive type, and ADHD/Combined type) into a single ADHD diagnosis group when investigating cognitive functioning.

Murphy and colleagues (2001) have argued that there are no differences in terms of cognitive performance among different subtypes of adult ADHD samples. However, considering the heterogeneous nature of ADHD (although sufficient evidence confirms that disruption of frontal lobe functions represents a core component of the disorder), each of the subtypes of ADHD is believed to have an independent neurological basis for the specific symptoms evidenced (Dinn, Robbins, & Harris, 2001). Therefore, differing neurological bases would be expected to differentially impact performances on neuropsychological tests.

Dysfunction in prefrontal regions, in general, produces cognitive difficulties in inhibition, in aspects of executive functions (e.g., working memory, organization, planning, and complex problem solving), and in attention among clinical ADHD population (Barkley, Grodzinsky, & DePaul, 1992; Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). Primary prefrontal regions specifically associated with these symptoms involve dorsolateral prefrontal cortex and orbitofrontal cortex. These two prefrontal brain systems are associated with different neuropsychological features of different ADHD subtypes: ADHD/Primarily hyperactive/impulsive subtype represents a predominant problem with inhibition and impulsivity, and ADHD/Primarily inattentive subtype represents a predominant problem with working memory (Dinn et al., 2001). Dinn and colleagues (2001) reported that the different ADHD subtypes exhibited predictably different patterns of performance on neuropsychological testing. These neurocognitive performance patterns of the ADHD subtypes were reflections of abnormalities in function and anatomically distinct subdivisions of the prefrontal region.

In the next section, these specific cognitive weaknesses associated with specific subtypes of ADHD are summarized.

1.4.3.1. Sustained attention with all types of ADHD symptoms

Sustained attention refers to the effective maintenance of attention over time (Lockwood, Marcotte, & Stern, 2001). Sustained attention impairment among ADHD adults is one of the most notable cognitive difficulties and a core feature of the disorder (Barkley, Murphy, & Kwansnic, 1996; Holdnack et al, 1995; Seidman, Biederman, Weber, Hatch, & Faraone, 1998). The mechanism by which sustained attention is disrupted may differ across subtypes. For example, individuals with the ADHD hyperactive subtype may have difficulties inhibiting disruptive effects on attention from extraneous stimuli in the environment, whereas individuals with the inattentive subtype may suffer from an internal inability to sustaining focused attention to the task. Regardless of the different causal mechanisms of poor performance, difficulties with sustained attention are evident in all ADHD groups.

The ability to sustain attention is believed to be mediated by the right frontal lobe, right anterior parietal lobe, and cingulate gyrus regions (Pardo, Fox, & Raichle, 1991; Stefanatos & Wasserstein, 2001). Localization of these neural systems for sustained attention in humans was confirmed using Positron Emission Tomography (PET) in healthy subjects and was evidenced regardless of the modality of sensory input (Pardo et al., 1991). When a task is lengthy, monotonous and boring, sustained attention functions are challenged (Kinsbourne, De Quiros, & Tocci Rufo, 2001).

Tests of sustained attention typically involve the sequential presentation of stimuli over time with instructions for a subject to engage in an appropriate targeted response

(Lezak, 1995). The stimuli usually consist of 60 or more items, displayed at a rate of one per second with a specific response required to each stimulus, to test sustained attention abilities (Strub & Black, 1988). One of the most popular measures of sustained attention (vigilance) is the CPT, which offers measures of accuracy and consistency of performance (DuPaul et al., 1992; Holdnack et al., 1995). In particular, the standard deviation of the median correct reaction time across repeated trials represents an individual's consistency in responding, reflecting the ability to sustain attention over time (Roccio & Reynolds, 2001).

Additionally, the pattern of the reaction times across test items in the CPT can reveal important information regarding sustained attention difficulties. People with sustained attention difficulties exhibited fading of sustained attention towards the end of a long series of test items, which can result in slowing of reaction times towards the end of the series and a decline of accuracy from loss of focus (Dinn et al., 2001). When a task is lengthy and boring, the initial novelty of the task dissipates with time (associated with more items on the task), and people with sustained attention weaknesses will not be able to maintain vigilant responding. Bradley and Golden (2001) reported general under-arousal of the brain during the latter part of the task as the reason for differential sustained attention problems between people with and without ADHD.

1.4.3.2. Disinhibition and impulsivity with hyperactive/impulsive symptoms

Dinn and colleagues (2001) suggest that the predominant behavioral problems with the hyperactive/impulsive type of ADHD are disinhibition and impulsivity. Disinhibition represents an inability to focus only on relevant information while ignoring irrelevant information to the task, and also can reflect an inability to suppress over-learned responses when a novel response is required (Barkley, 1997). Impulsivity is related to premature responding and inability to delay responding. Impulsivity, in this context, refers to difficulties in determining when actions should be emitted and in controlling the force and sequencing of those actions (Barkley, 1998). Failure of these behavioral control processes is a primary feature of the hyperactive symptoms of ADHD patients. Neuropsychological tasks that are sensitive to orbitofrontal region dysfunction assess response inhibition and impulsivity (Dinn et al., 2001).

One of the most frequently used neuropsychological tasks for the assessment of response inhibition is the Stroop Color-Word task (Stroop interference test). The Stroop test measures an individual's ability to inhibit the prepotent response (dominant response tendency) in order to produce a less dominant response, and the Stroop test can differentiate ADHD groups from controls (e.g., Barkley, Grodzinsky, & DuPaul, 1992; Sergeant, Geurts, & Oosterlann, 2002) even after correcting for basic reading and naming speed (Lufi, Cohen, Parish-Plass, 1990; MacLeod, & Prior, 1996). That is, people with ADHD were significantly slower to complete the interference trials because of the lack of successful inhibition of other irrelevant but dominant responses.

More recently, computerized tests such as the Continuous Performance Test (CPT) have been successful in discriminating ADHD from non-ADHD controls (Ballard, 2001). In the typical CPT test, letters are presented visually, one at a time and at a fixed rate, and the subject presses a lever whenever the letter "X" appears and inhibits responding in any other cases (X-type CPT). Variations of the basic CPT are also available: n-back CPT, in which subjects respond if the target letter matches a preceding letter of some specific number of steps before the target (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). In the example of a one-back CPT (n-back=1), subjects press a lever in response to the target (e.g., “X”) when it is immediately preceded by a specific letter (e.g., “S”), and inhibits pressing the lever in any other cases (all other letters and even the “X” if not following “S”). Rosvold and colleagues (1956) reported that the basic X-type CPT correctly distinguishes subjects with and without problems in the brain, and this discriminatory value of the task increases with increased difficulties of CPT (e.g., one-back-, two-back-, three-back types). Because the task is computerized, reaction time, accuracy data, and response time variability across repeated trials are available. This task can provide measures of impulsivity or inability to inhibit a response (Ballard, 2001).

Using the Stroop test and CPT task, the disinhibition problems have been demonstrated in ADHD samples; however, the existence or the magnitude of the disinhibition problem has not been examined in non-clinical samples along a continuum of ADHD symptoms.

1.4.3.3. Working memory with inattentive symptoms

The predominant problems associated with the inattentive type of ADHD are working memory deficits. Working memory requires three components: the central executive, visuospatial sketchpad, and phonological loop (Baddeley, 1986). The central executive is the working memory component that coordinates all the executive decision-making processes, whereas the latter two systems are slave systems that serve the central executive and contribute to simple short-term memory for visual (visuospatial sketchpad) and auditory (phonological loop) processing (Baddeley, 1986). The central executive component of working memory entails active cognitive processing and manipulation of material in order to produce a new response while passively holding information in short-term storage (Baddeley, 1986).

Neuropsychological tasks that are sensitive to disruption of the dorsolateral prefrontal cortex region are tests that examine working memory functions (Iversen & Dunnett, 1990). Using monkeys with bilateral lesions to the mid-dorsolateral prefrontal cortex, this cortical area was found to be related to accurately performing tasks requiring working memory (Jacobson, 1935). As a component of the executive controls that are affected by dysfunctions in the frontal lobe, working memory deficits are expected to be evident among ADHD samples that have primary inattention problems. In fact, adults with ADHD have documented problems with working memory tasks such as Digit Span backward (Woods, Lovejoy, & Ball, 2002; Barkley, 1997).

In summary, cognitive difficulties are documented in adult clinical ADHD samples, involving attention and executive functioning systems. Based on the clinical studies, dysregulation of specific areas of the frontal region are found to result in specific cognitive weaknesses: (1) for all subtypes, sustained attention difficulties are reported, (2) individuals with ADHD primarily hyperactive/impulsive subtype demonstrate difficulties predominantly with disinhibition and impulsivity, (3) those with ADHD primarily inattentive subtype exhibit difficulties with working memory. Distinct neuroanatomical features are purported to be responsible for these corresponding difficulties.

1.5. Present study

Despite the evidence connecting specific cognitive difficulties to specific regions of prefrontal cortex, there is a strong tendency to consider ADHD as an unidimensional disorder without considering these specific subtypes. Furthermore, there is a dearth of knowledge of how these specific ADHD symptoms are related to the respective aspects of cognitive processing in non-clinical ADHD samples. Considering the hypothesized neural mechanisms underling symptoms of specific subtypes of ADHD and the limitations of diagnosing adults with ADHD based on the dichotomous approach of DSM-IV, it is conceivable that adults with a large number of ADHD symptoms may, nevertheless, exhibit relative cognitive weaknesses that are similar to those with clinically significant ADHD. If the severity and number of ADHD symptoms experienced are directly related to the degree of cognitive difficulties, then it is possible that adults with sub-clinical symptoms of ADHD, may also experience behavioral problems resulting from the cognitive difficulties (e.g., academic underachievement/difficulties, difficulties at work, a lack of satisfaction in interpersonal relationships). Such associations may provide targets of future intervention studies in individuals with sub-clinical ADHD. Therefore, it is important to quantify the relationship between symptoms of ADHD and the cognitive difficulties among non-clinical samples.

The aim of the present study was to evaluate attention and executive functions as they relate to ADHD symptoms in a non-clinical sample of adults who vary in degree of self-reported ADHD symptoms. In particular, attention (sustained attention) and executive dysfunctions (lack of inhibition/impulsivity, working memory difficulty) related to ADHD symptoms on a continuum were addressed. The properties of inhibition and impulsivity, executive working memory functioning, and sustained attention were evaluated using traditional as well as sensitive computerized measures.

1.5.1. Hypotheses

The central hypothesis of the present study was that non-clinical adults with higher ADHD symptoms would display poor performance on measures of sustained attention, disinhibition/impulsivity, and working memory functioning as compared to individuals with lower ADHD symptoms. It was further hypothesized that the associations between sub-clinical ADHD symptomatology and cognitive measures would persist after statistically adjusting for demographic variables (e.g., age, gender, years of education). The rationale for the hypothesis was that ADHD is a result of dysregulation of the frontal lobe region (along with other brain regions), and the predominant symptoms of ADHD reflect the brain regions that are primarily affected. These compromised brain functions, in turn, should be reflected in performance measures documented with neurocognitive assessment tools. The operational model of the current study based on the literature review is presented in Figure 1.

Insert Figure 1 about here

In the present study, frequently used neuropsychological measures in ADHD research, along with a few novel measures, were used to examine the relationship between symptoms of ADHD and cognitive difficulties. The computerized Running Memory Test reaction time and variability (standard deviation) scores in addition to the Digit Span Forward consistency score were used as measures of sustained attention and were anticipated to be correlated with the total ADHD symptoms. The Stroop test interference completion score and a computerized Running Memory Test accuracy score were used as inhibition and impulsivity measures, respectively, and were expected to be correlated with the ADHD hyperactivity/impulsivity subtype scores. The Digit Span Backward total raw score and the Letter Number Sequencing total raw score, and the computerized Match to Sample accuracy score were used as measures of working memory and were hypothesized to be correlated with the ADHD inattentive subtype scores. Because there are three cognitive constructs that were involved in this investigation (sustained attention, inhibition/impulsivity, and working memory), three specific hypotheses and associated sub-hypotheses were addressed in this investigation.

Hypothesis 1: Sustained attention performance would be inversely correlated with total symptoms of ADHD:

Individuals with higher self-reported total ADHD symptoms would exhibit poorer sustained attention performance.

Hypothesis 1a. Higher **total symptom scores** would be associated with poorer performance on measures of sustained attention, represented in smaller consistency in the **Digit Span forward** test.

Hypothesis 1b. Higher **total symptom scores** would be associated with poorer performance on measures of sustained attention, represented in larger choice reaction time variability in a **Running Memory** CPT task.

Hypothesis 1c. Groups at the upper and lower extremes of **total symptoms** would exhibit differential polynomial trends across repeated trials of a sustained attention task, represented in the choice reaction times in the **Running Memory** CPT task. Specifically, the group with lower self-reported total ADHD symptoms would have a significant linear trend across trials, and the group with higher ADHD symptoms would have a significant non-linear (variable) trend in their sustained response across repeated trials within a single task.

- *Rationale:* Sustained attention is expected to be decreased because of the presence of ADHD symptoms related to general hypoarousal of the brain and lack of activation in the frontal lobes and right parietal lobe. Therefore, it was postulated that subjects with higher total scores of ADHD overall would have more sustained attention problems. Sustained attention has been associated with right frontal and parietal lobe functioning and is affected by general arousal level. Based on the continuum model of ADHD symptoms, those individuals endorsing overall symptoms of ADHD were expected to perform more poorly on sustained attention tasks.

<u>Hypothesis 2</u>: Disinhibition and Impulsivity would be correlated with Hyperactive/impulsive symptoms:

Higher scores on self-reported hyperactivity/impulsivity symptoms would be related to more disinhibition and impulsivity.

<u>Hypothesis 2a</u>. Disinhibition: Higher **hyperactive/impulsive symptom** scores would be associated with poorer performance on measures of inhibition, represented in longer time to complete the interference trial of the **Stroop** task.

<u>Hypothesis 2b</u>. Impulsivity: Higher **hyperactive/impulsive symptom** scores would be associated with poorer performance on measures of impulsivity, represented in less accuracy on the **Running Memory** task.

- *Rationale*: It was postulated that people with more symptoms of hyperactivity and impulsivity would exhibit more difficulties on the tests that require inhibition of dominant and impulsive responses which are sensitive to the orbitofrontal region of prefrontal function (Dinn et al., 2001). Based on the continuum model of ADHD, individuals endorsing more hyperactivity/impulsive symptoms were expected to perform more poorly on these specific tasks because of relatively greater difficulties with suppressing/inhibiting their dominant/well-learned responses.

Hypothesis 3: Working memory performance would be inversely correlated with Inattentive symptoms:

Higher self-reported inattentive symptom scores would be related to poorer working memory performance.

Hypothesis 3a. Verbal/Auditory Working Memory: Higher **inattention symptom scores** would be associated with poorer performance on a measure of verbal working memory, represented in lower **Digit Span backward** raw score.

Hypothesis 3b. Verbal/Auditory Working Memory: Higher **inattention symptom scores** would be associated to poorer performance on a measure of verbal working memory, represented in lower **Letter-Number sequencing** raw score.

Hypothesis 3c. Visual Working Memory: Higher **inattention symptom scores** would be associated with poorer performance on a measure of visual working memory, represented in lower accuracy in a **Match to Sample** task.

- *Rationale*: It was postulated that subjects with higher inattentive symptom scores would have more difficulties in working memory tasks which are sensitive to dorsolateral prefrontal cortex dysfunction (Dinn et al., 2001). Based on the continuum model of ADHD symptoms, those individuals endorsing more inattentive symptoms were expected to perform more poorly on these specific tasks.

2. Methods

2.1. Participants

The sample consisted of 76 participants who were administered a variety of self-report questionnaires and cognitive performance tasks as part of a larger study (USUHS, protocol G183LZ). This larger study investigated the impact of the combined effects of Pyridostigmine, Deet, and Permethrin on physical and cognitive performances under stress (PB study). The PB study was conducted at two sites: the Uniformed Services University of the Health Sciences, Bethesda, MD, and the Naval Health Research Center, San Diego, CA. The sample consisted primarily of active duty military members. Institutional Review Board approval was obtained for data collection in the larger study and for the data analyses in the present project (USUHS, protocol TO72GJ, see Appendix A).

The larger study included both men and women of all ethnic backgrounds, between the ages of 18 and 49. Exclusion criteria in the larger study included history of psychiatric disorders, medical diagnosis with diabetes, coronary artery disease, hypertension, morbid obesity, osteoarthritis, or other chronic joint, muscle, or nervous system disorder. These exclusion criteria were used because these conditions may be associated with altered response to the stress condition of the study and because such conditions usually exclude individuals from military deployment. Each participant's data were given a new identification code to ensure confidentiality for the current study.

To be included in the analyses of present study, participants had to have completed the Murphy and Barkley's ADHD questionnaire, and the selected neuropsychological tests in the larger project. Of the 87 total participants screened for the current study, 76 had completed the required questionnaires and some of the selected neuropsychological tests. For the current study, exclusion criteria were that subjects should not meet both a history of diagnosis with ADHD and endorsement of current symptoms of ADHD in the study measures that met the DSM-IV diagnostic criteria for adult ADHD. The total sample size remaining was 75, after excluding one person who had been diagnosed with ADHD in childhood and also met the current ADHD diagnostic criteria on the study measures. The final sample for the current study was aged between 20 and 49 years (mean=28 years; SD=5.7), of all ethnicity and with varying levels of education. Descriptive information of the study sample is provided in Table 1.

Insert Table 1 about here

2.2. Measures

Overview: Basic demographic and psychosocial history information was collected to characterize the sample. Next, self-report questionnaires (Murphy and Barkley, 1998) were used to assess the number and degree of ADHD symptoms reported by the participants. In addition, two computer-based tasks (Matching to Sample and Running Memory, subsets of a larger computerized performance assessment battery), and selected paper-and-pencil neurocognitive tests (Stroop, Digit Span, and Letter-Number Sequencing tasks) were used to measure the level of inhibition/impulsivity, working memory, and sustained attention as they relate to reported ADHD symptoms.

2.2.1. History Information*:* As a part of the larger study, participants completed a self-report measure examining history of ADHD: participants were asked to answer if they were ever evaluated, diagnosed, and/or treated for ADHD. The presence of any of these conditions did not disqualify any subject from the present study unless the person specifically reported both a history of ADHD and active current symptoms of ADHD on the study measure at levels that met clinical diagnostic criteria.

***2.2.2. Childhood Behavior- and Current Behavior-Self Report Forms Questionnaire (Murphy, & Barkley, 1998)*:** This questionnaire is a sub-section of Murphy and Barkley's (1998) clinical workbook and was administered in the larger study for evaluating symptoms of ADHD defined by the DSM-IV (APA 1994). Standardization of these measures was based on a convenience sample of 720 adults presenting for renewal of driver's licenses in Massachusetts, and normative data is provided (Murphy & Barkley, 1996b). The questionnaire is a direct application of the DSM criteria, and the questions have high face validity (see Appendix B). Cronbach's alpha of .926 was obtained using the data from the current study.[1]

The Murphy and Barkley ADHD questionnaire was chosen because: (1) it is relatively easy and short to administer; (2) the questionnaire is easy to score; (3) it is direct application of the DSM-IV diagnostic criteria; and (4) summation of scores can be used as continuous variables in the analyses to quantify the magnitude of ADHD symptoms that were reported. This compilation of the scores emphasizes a dimensional approach for evaluating reported ADHD symptoms instead of a criterion-based categorical approach for diagnosing ADHD in this non-clinical sample.

The questionnaire consists of two parts: childhood symptoms in retrospect, and current symptoms as adults. For each self-report form, 18 questions directly reflect the DSM-IV ADHD symptoms associated with the two ADHD subtypes (inattentive, and

[1] Overall reliability of the Murphy and Barkley's ADHD scale is provided in the workbook, however, it was necessary for Cronbach's alpha to be recalculated because only sub-parts of the Murphy and Barkley's ADHD scale were used in the current study. Specific sub-parts were those pertaining to the self-report forms of ADHD symptoms. Cronbach's alpha represents internal consistency based on the average inter-item correlation.

hyperactive/impulsive). The 18 questions consist of nine symptoms related to inattention and nine symptoms related to hyperactivity/impulsivity. Each symptom is measured on a 4-point Likert scale with the anchors 0 (Never or rarely) and 3 (Very often), allowing quantification of the number and degree of symptoms.

In the current study, three different symptom scores were generated: Hyperactive/impulsive, Inattentive, and Total scores. The Hyperactive/impulsive symptom score was obtained by adding the Likert scores for each item addressing hyperactivity/impulsivity symptoms across both the childhood and current behavior forms (even-numbered items; possible score range 0 to 54). The Inattentive symptom score was calculated similarly by adding inattentive symptoms across the childhood and current behavior forms (odd-numbered items; possible score range 0 to 54). An overall total ADHD score was calculated by adding the Likert scores for all items across both the childhood and current behavior report forms.

The data can be organized to reflect the childhood and current symptoms of ADHD as well. However, as the literature in ADHD research suggests, the sub-types of ADHD and particular symptoms associated, are purportedly specific to distinct neuroanatomical and functional features of dysregulation. Neuroanatomical features related to the sub-types of ADHD may not change over time, although the compensation may occur with age. Therefore, it is more consistent with the literature to organize the scores by neuropsychological features and associated symptoms of ADHD, rather than organizing the scores by time of symptom presentation.

Each participant’s potential score for the total combined childhood and current ADHD score could range from 0 to 108. For the hypothesis 1c, based on the total ADHD symptom score, two ADHD groups were formed and separate analyses were run for each group: the groups are denoted as low (L) and high (H) symptom groups, representing the respective bottom 33% and top 33% of the total participants.

2.2.3. Traditional Neurocognitive Tests: The traditional neurocognitive tests were paper-and-pencil tasks that were administered by an examiner. These tests were selected from the larger protocol based on their expected relation to symptoms of ADHD.

2.2.3.1. Stroop Neuropsychological Screening Test (SNST) (Stroop, 1935; Trenerry, Crosson, DeBoe, & Leber, 1989): SNST is a test of executive functioning efficiency that tests response inhibition (Farah, 2003). The Stroop color-naming test requires overriding of a dominant response, and it has established solid content validity[2] (Boone, Miller, Lesser, Hill, & D'Elia, 1990; Spreen & Strauss, 1998), which allowed successful distinction of the people with problems with and without inhibition in the close head injury (Trenerry et al., 1989) and ADHD samples (Murphy, Barkley, & Bush, 2001; Lovejoy et al., 1999). SNST has been standardized on 156 adults ages 18-79 years, and it has excellent test-retest reliability of .90 (Trenerry et al., 1989).

SNST requires the ability of individuals to inhibit their over-learned dominant response and adapt to a novel task. The participants are presented with two sheets of paper separately with words on them, and are instructed to read words on the first sheet, and then name colors of the words that are printed on the second sheet. The words are printed in color either in blue, red, green, or tan, and the words also spell "blue," "red,"

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[2] Validity is the extent to which a test measures what it is supposed to measure. In neuropsychology, one way to establish validity of the measures is to establish content validity. Content validity is similar to face validity: if the test *looks* like a valid measure, then content validity is established (Murphy & Davidshofer, 1991). However, content validity is based on agreement among expert judges in the field with regard to a detailed description of the content domain that is measured by each test (Mitrushina, Boone, & D'Elia, 1999).

“green,” or “tan.” The over-learned activity is reading. The novel activity is naming the color while actively inhibiting the dominant response of reading the incongruent color name words (e.g., state the color of the ink, which differs from the color name that is written). The data of interest for examining the performance of the Primarily Hyperactive ADHD subtype are the completion times for the interference trial (naming incongruent colors). SNST data are excluded if a subject is color blind.

2.2.3.2. Digit Span Forward and Backward: The Digit Span task is a part of the Wechsler Adult Intelligence Scale (3rd Edition) (*WAIS-III*) (Wechsler, 1997). The Digit span has content validity for simple attention test and working memory test because the forward task requires simple citation of the numbers and backward task requires the activation of both executive control and one of the slave systems of working memory, respectively. Test-retest reliability ranges from .66 to .89, depending on interval length and subjects’ age (Matarazzo & Herman, 1984; Snow et al., 1989).

The test consists of two parts: Forward and Backward. The Digit Span Forward requires simple recital of the number series that has been read by an examiner. It is closely related to the efficiency or span of attention rather than memory (Lezak, 1995). A forward consistency score (the number of digit that an individual repeated correctly across consecutive trials of the same span length) can represent a measure of consistent performance as a result of sustained attention.

Digit Span Backward requires transient storage of a recited number series, and repetition of the numbers in reverse. For instance, if the examiner says, 7-1-9, then the subject should say, 9-1-7. This test is a verbal working memory test that requires subjects to listen to the digits, to hold them in the short-term memory store, and to manipulate the digits (reverse them) to produce the new output. Digit Span backward is found to be a good measure of working memory in clinical ADHD samples (Kovner et al., 1998; Barkley et al., 1996; Milich & Loney, 79). The data of interest are the total raw scores of the backward condition as a working memory measure and maximum consistency scores of the forward condition as a sustained attention measure.

2.2.3.3. Letter-Number Sequencing (WAIS-III, Wechsler, 1997): Letter-Number Sequencing is a subtest of the Wechsler Adult Intelligence Scale that directly tests working memory, and has content validity because it requires the activation of both executive control and one of the slave systems of working memory. Split-half reliability ranges from .82 to .88 (The Psychological Corporation, 1997).

A group of numbers and letters are read to a subject. Upon hearing, the subject's task is to say the numbers first, in order, starting with the lowest number, and then say the letters in alphabetical order. For example, if the examiner says 9-C-3, then the subject's answer should be 3-9-C. This task is a measure of verbal working memory that requires short-term memory, manipulation of the input, and production of a new output. The data of interest are the total raw scores as a working memory measure. The Letter Number Sequencing task has not been reported specifically in ADHD patients, but because it requires components of working memory (Wechsler, 1997), the results from this task should be similar to the outcome of the Digit Span tasks.

2.2.4. The NASA-1 Spaceflight Cognitive Assessment Tool for Windows (WinSCAT): WinSCAT has a five-subtest battery that is adapted from the Automated Neuropsychological Assessment Metrics battery (ANAM-Version 3.11) (Reeves et al., 1992). This battery tests basic visual search/attention processing speed, delayed recall, visuospatial working memory/attention, speeded arithmetic calculations, and sustained attention abilities. Among these five subtests, the Visual Matching to Sample test (visual working memory) and Running Memory test (a one-back continuous performance test) were used to examine the relative weaknesses in cognitive components in relation to the level of ADHD symptoms reported in our non-clinical sample.

2.2.4.1. Matching to Sample test: This test measures visual working memory. Because the task requires visual memory recognition after a delay, involving storage of information, holding of that information over the delay, and selection of the correct response, it has content validity. In addition, Match to Sample is significantly correlated (construct validity) with Digit Span backward, which is one of the most commonly used measures of working memory (Kabat et al., 2001). Using fifty-six participants from the larger study, test-retest stability coefficient was determined. The test-retest coefficient over the mean retest interval of 6.4 days was excellent (.86).

For each trial, the participant is briefly shown a single 4 by 4 red and white target block design in the center of the monitor. After the target design disappears, two choice designs are presented following a brief delay. The participant presses the left finger mouse key if the left figure is identical as the target design, and presses the right finger mouse key if the design on the right is identical as the target design. The accuracy score is examined as a measure of the delayed visual working memory.

2.2.4.2. Running Memory test: The Running Memory test, a variation of the Continuous Performance test, is used to assess lapses in attention (vigilance/sustained attention) and impulsivity and has content validity (Spreen & Strauss, 1998: Epstein, Johnson, Varia, & Conners, 2001). Using the larger study data of forty-one participants, test-retest stability coefficient was determined. The test-retest coefficient over the mean retest interval of one week was good (.79)[3].

In the center of the screen, a series of single digit numbers are presented briefly. The subject is instructed to left click the mouse if the number flashing on the screen is the same as the number presented immediately before the existing flashing number. If the numbers are different, then the subject is to click the right mouse key. The Running Memory test is a continuous performance, choice reaction time test using a one-back paradigm that requires sustained attention for a period of time. The subject has to decide if the current letter displayed on the screen is the same or different from the previous (one-back) letter. The data of interest are accuracy to measure impulsivity and variability of the choice reaction times (standard deviation) to measures sustained attention.

In addition, the variability in the successive raw choice reaction times for each stimulus across trials within one session (160 trials of reaction time) is used to examine the two extreme levels of ADHD total symptom report (top and bottom 33% of total ADHD symptom score groups). From the original total 160 trials, consecutive trials are summed and averaged in groups of 40-trial blocks, to yield a total of four successive choice reaction time sets for the two groups. These points are referred to as Set 1, Set 2, Set 3, and Set 4 to denote the sequential average of each set of 40 consecutive trials. To illustrate the pattern of sustained attention in individuals with different levels of severity of ADHD symptoms, the reaction time scores across test items on the Running Memory Test are plotted for the two extreme groups. The data are characterized as invalid and excluded if the accuracy on the task is less than 69% or the number of lapses (“no

[3] The test-retest coefficient was calculated using the data set from the larger study that administered WinSCAT over a period of time before the experimental manipulations.

response” trials) is more than 31. These cutoff scores are chosen because these scores in a normal sample usually indicate that the subject do not understand the task, and the resulting score is therefore not a correct representation of the individual’s performance ability.

2.3. Data Analyses

Data were analyzed using SPSS for Windows Version 11 (SPSS Inc, Chicago, Illinois). All of the study hypotheses were tested using multivariate regression or repeated-measures trend analyses (Cohen & Cohen, 1983; Keppel, 1991). Bivariate correlation analysis was first conducted to examine the associations among all the study variables. The study variables were then entered in a hierarchical linear regression model after accounting for the control variables of site, gender, age, and level of education. All regression models used three blocks: the first block entered control variables associated with study site, gender, and age; the second block with years of education; and the third block with the specific ADHD scores associated with the hypothesis. The hypotheses that were tested using a hierarchical linear regression model were the performances on inhibition, impulsivity, working memory, and sustained attention tasks in relation to specific ADHD measures.

Polynomial trend analyses examining each of the two extreme groups (respective bottom 33% and top 33% of the total participants as stated in section 2.2.3.2) tested the sub-hypothesis (H3c). Polynomial trend analysis across repeated trials was conducted separately for each extreme group to examine the stability of performance for the high and low ADHD total symptom score groups across repeated trials. For all the analyses, two-tailed tests were performed with the significance level (α) set at 0.05.

Power analysis, based on power of 80 and a test significance level (α) set at .05, determined that 50 participants were needed to show an additional .12 increase in R^2 in the multiple linear regression model which already includes 4 variables (site, gender, age, and years of education) with an squared multiple correlations (R^2) of .16. However, since the data for the study came from the larger existing data set, we have used all valid data and have over-sampled the data when possible.

3. Results

The presentation of results is organized as follows: (1) descriptive summaries of the independent and dependent measures; (2) correlational analyses; (3) results from testing of the hypotheses based on hierarchical regression and polynomial trend analyses.

3.1. Descriptives

The mean scores, standard deviations, and ranges on the Hyperactive, Inattentive, and Total ADHD independent measures are presented in Table 2.

Insert Table 2 about here

The descriptive summaries of the selected traditional neuropsychological tasks and computerized cognitive tasks as dependent variables are presented in Table 3. Total numbers of participants included in the data analyses are different for some measures because either participants withdrew from the study at different points, some data were not available or invalid because of computer error. For the Running Memory test, 56 participants' data were available. Of those, eight participants' data met exclusion criteria (either the accuracy is less than 69% or the number of lapses is more than 31). Because of the suspicion that these participants' poor performance may be the reflection of attentional problems related to ADHD, analyses of variance were conducted to examine the potential differences between these groups of participants who met and did not meet the criteria. The analyses revealed no significant differences between these two groups in any ADHD measures (date not shown).

Insert Table 3 about here

3.2. Correlational Analyses

Bivariate correlation analyses were first conducted to examine the correlation among dependent variables, selected ADHD measures, and demographic variables (See Table 4). Examining the distribution of the data, violations of normality were suspected with some of the variables. Therefore, non-parametric Spearman correlation analyses were conducted. The results from these non-parametric analyses closely resembled results obtained from parametric correlation analyses (Pearson); further results are based on untransformed data parametric analyses.

Insert Table 4 about here

As expected, the number of years of education was significantly correlated with all of the traditional and computerized neurocognitive measures. However, contrary to expectations, none of the ADHD measures were significantly correlated with traditional or computerized measures. More detailed correlational analyses are provided in Tables 4a (total ADHD symptoms), 4b (inattentiveness), and 4c (hyperactivity/impulsivity). The data indicate that childhood symptomatology revealed stronger associations with neuropsychological measures as compared to current adult ADHD symptomatology (see additional analyses presented in section 3.3.3).

Insert Table 4a, 4b, and 4c about here

3.3. Multivariate Hierarchical Regressions

3.3.1. Hypothesis 1 – Sustained attention as it relates to total ADHD symptoms

<u>Hypothesis 1a. Digit Span forward</u>

The hypothesis is that higher total ADHD symptoms will be related to lower consistency on Digit Span. Results are presented in Table 5.

Insert Table 5 about here

Hierarchical regression (examining three sets: (1) demographics; (2) education; and (3) total ADHD symptoms) with Digit Span forward consistency as the dependent variable indicated that the model was significant (R^2 =. 185, F (5,68), p<. 01). However, the total symptom scores of ADHD alone did not explain a significant amount of the variance in the Digit Span forward consistency score after the other control variables are entered into the model.

<u>Hypothesis 1b. Running Memory response time deviation</u>

Insert Table 6 about here

The results of the three block hierarchical regression with the Running Memory standard deviation response time as the dependent variable indicated that the model was not significant (see Table 6). Additionally, the total symptom scores of ADHD alone did not explain a significant amount of the variance in the Running Memory task performance after controlling for the other variables.

<u>Hypothesis 1c. Running Memory response time</u>

Using the four-point averaged response time of the Running Memory task, sustained attention hypothesis was examined. There were significant main effects (within-subjects effects (F (3, 129)=7.937, p<.001) and between subjects effects (F (1,43)=4.267, p<.05)) without a significant interaction term between groups over time.

However, because different patterns of sustained attention over time between groups were hypothesized, detailed analyses of simple effects were conducted. Repeated measures analyses of polynomial trends revealed the low total symptom ADHD group had a significant linear trend ($F=6.342$, $p<.05$) (see Figure 2), and the high total symptoms ADHD group had a significant cubic trend ($F=4.651$, $p<.05$) (see Figure 3). The figures are presented with standard error of means.

Insert Figure 2 and 3 about here

3.3.2. Hypothesis 2 –Disinhibition and Impulsivity as it relates to hyperactive/impulsive symptoms

Hypothesis 2a. Stroop time

The results of the sub-hypothesis testing whether higher hyperactive/impulsive symptom scores would be correlated with significantly longer times to complete the Stroop Color-Word task after accounting for study site, gender, age, and years of education are presented in Table 7.

Insert Table 7 about here

The results of the three block hierarchical regression with the Stroop Color-Word completion time as the dependent variable indicated that the model was not significant. The total hyperactive/impulsive symptom scores alone did not explain a significant amount of the variance in the Stroop Color-Word performance after accounting for the other control variables. The self-reported hyperactive/impulsive symptom score alone did not explain the performance on inhibition.

Hypothesis 2b. Running Memory accuracy

The results of analysis of higher hyperactive/impulsive symptoms scores relating to poorer Running Memory accuracy are presented in Table 8.

Insert Table 8 about here

Hierarchical regression with the Running Memory task accuracy as the dependent variable indicated that the overall model was significant (R^2 =. 294, F (5, 42), p<. 001). The total hyperactive symptom scores also explained a significant amount of the variance in the Running Memory performance after accounting for the other control variables (R^2 change= .087, F (5, 42), p<. 05). The results indicated that higher total hyperactive scores were related to poorer accuracy in the Running Memory performance.

3.3.3. Hypothesis 3- Working memory as it relates to inattentive symptoms

It was posited that higher total inattentive symptom scores would be associated with significantly lower scores on verbal (Digit Span backward and Letter-Number Sequencing) and visual (Match to Sample) working memory tasks, after accounting for controlling variables.

Hypothesis 3a. Digit Span backward

Insert Table 9 about here

The results of the hierarchical regression with the Digit Span backward performance as the dependent variable indicated that the overall model was significant (R^2 =. 095, F (5,69), p<. 05) (see Table 9). The total inattentive symptom scores of ADHD alone did not explain a significant amount of the variance in the Digit Span backward performance after accounting for the other control variables. However, the inattentive score had a marginal significance (p=. 066) in the predicted direction: there was an inverse relationship of the Digit Span backward performance and the total inattentive symptom scores. In addition, the overall model was not significant until the addition of the third block (inattentive symptoms measure). Therefore, the inattentive symptom score adds to the explained variance of the overall model.

Additional Analysis:

The following analyses were conducted to further clarify the relationship between inattention symptoms and the Digit Span performances. The ADHD inattention score used in the above analysis was generated by adding the childhood and current inattentive symptom scores together. Because we aimed to further examine whether the marginally significant Digit Span task results reflected current or childhood ADHD symptoms, we separated two inattentive symptom scores (childhood and current symptoms) and conducted hierarchical regression as usual using each of these new inattentive scores as the predictor (see Table 4a and 4b). The results of these additional analyses with the Digit Span task revealed a significant contribution by childhood symptoms only. The results of the analysis with the childhood inattention symptom are presented in Table 10.

Insert Table 10 about here

The results of the three-block hierarchical regression with the childhood inattentive score as the predictor and the Digit Span backward raw score as the dependent variable indicated that the overall model was significant (R^2 =. 148, F (5, 96), p<. 01). In addition, the childhood inattentive symptom score explained a significant amount of the variance in the Digit Span backward performance after accounting for the other control variables (R^2 change= .092, F (5, 69), p<. 01). The analysis revealed that that the childhood inattentive symptom explained the current performance on a working memory measure.

<u>Hypothesis 3b. Letter-Number sequencing score</u>

The results of the three block hierarchical regression with the Letter-Number Sequencing task as another working memory measure as the dependent variable are presented in Table 11.

Insert Table 11 about here

This analysis indicated that the overall model was significant (R^2 =. 130, F (5,69), p<. 05). However, the total inattentive symptom scores of ADHD alone did not explain a significant amount of the variance in the Letter-Number Sequencing performance after accounting for the other control variables.

<u>Hypothesis 3c. Match to Sample accuracy</u>

Insert Table 12 about here

The results of the visual working memory sub-hypothesis are presented in Table 12. The results of the three block hierarchical regression with the computerized visual working memory measure (Match to Sample), as the dependent variable indicated that the overall model was not significant. The total inattentive symptom scores of ADHD alone did not explain a significant amount of the variance in the Match to Sample performance after accounting for the other control variables.

3.4. Supported and Unsupported Hypotheses

H1. Sustained attention and total symptoms

a. Higher total symptom scores would be associated with poorer performance on the Digit Span forward consistency: **Not supported**

b. Higher total symptom scores would be associated with poorer performance on the Running Memory choice reaction time variability: **Not supported**

c. A group with lower self-reported total ADHD symptoms would have a significant linear trend, and a group with higher ADHD symptoms would have a significant non-linear trend in their sustained performance: **Supported**

H2. Disinhibition and Impulsivity and Hyperactive/impulsive symptoms

a. Higher hyperactive/impulsive symptom scores would be associated with poorer performance on the Stroop interference task: **Not supported**

b. Higher hyperactive/impulsive symptom scores would be associated with poorer performance on the Running Memory task accuracy: **Supported**

H3. Working memory and Inattentive symptoms

a. Higher inattentive symptom scores would be associated with poorer performance on Digit Span backward: **Partially supported**

Additional Analysis revealed that the childhood inattentive scores had a significant inverse correlation with the Digit Span backward performance.

b. Higher inattentive symptom scores would be related to poorer performance on Letter-Number sequencing: **Not supported**

c. Higher inattentive symptom scores would be associated with poorer performance on the Match to Sample accuracy: **Not supported**

4. Discussion

In clinical ADHD samples, difficulties with sustained attention, inhibition, control of impulsive behavior, and working memory are consistently reported. The current study extended these findings into a non-clinical sample using a continuum model and examined the relationship among hyperactive/impulsive, inattentive, and total symptoms scores with performance on measures of inhibition and impulsivity, working memory, and sustained attention, respectively. Some of the results obtained from a non-clinical sample replicated findings in the clinical ADHD population. The discussion section is organized in the following order: discussion specific to hypotheses, general discussion, limitations, implications, and future directions based on the finding from the current study.

4.1. Discussion of supported and unsupported hypotheses

4.1.1. Hypothesis 1: Sustained attention in relation to total symptoms

The hypothesis of sustained attention which posited that the total ADHD symptom scores would explain a significant proportion of the Digit Span forward consistency and Running Memory choice reaction time variability was not supported. The Digit Span forward task ranged from three to nine digits in span length, and two trials were administered for each span length until a participant gave incorrect answers for both trials at a given length. The maximum span that the individual can repeat back accurately represents the individual’s simple attention span capacity. However, a second measure that can be derived from this test is the consistent span length, representing the highest digit span length for which both trials were continuously correct. It was our intention to capture the participants’ mistakes due to sustained attention problems before they have actually reached their simple attention capacity. For instance, a problem with sustained attention was evidenced if a participant made a mistake with one of the two four digit span length trials, but proceeded successfully with a longer span length of digits. A lower consistent span length thus demonstrated difficulty with sustained attention across the entire task. However, consistent span length was not predicted by the combined symptoms total score, and the hypothesis was not supported by this measure.

One possible explanation for a null finding with the consistent span length measure is the short duration of the task. According to Strub and Black (1985), sustained attention demonstrated by consistency of performance across trials can differentiate a clinical group with sustained attention deficits from a non-clinical group in 60 consecutive trials, read or displayed at a rate of one per second. The digit span forward may have been too short a task to evaluate sustained attention, particularly, along a continuum in a normal sample.

With regard to response time variability in the running memory task, it was hypothesized that higher total ADHD symptom scores would be correlated with more variability in choice reaction time because problems with sustained attention would result in inconsistent response times. As with the Digit Span forward consistency score, this hypothesis was not supported. When the pattern of reaction time score changes across the 160 trials of the Running Memory task were examined for each participant, almost all individuals demonstrated improvements in their response times, as represented faster response times over repeated trials. In other words, slower response times for all participants during the earlier trials of the task created larger variability in all participants and thus, obscured any overall variability independent of learning effects during the earlier trials.

The third part of the sustained hypothesis, which used raw inattention scores, did demonstrate polynomial trends across repeated trials of the Running Memory consistent with the hypothesis: the low total ADHD symptom group (bottom 1/3 of the total ADHD symptoms scores) demonstrated a significant (negative) linear trend, and the high total ADHD symptom group (top 1/3 of the total ADHD symptom scores) produced a significant non-linear trend. However, it should be made clear that there was no significant interaction between groups and repeated measures. In the absence of a significant interaction term, further examination of simple effects is generally discouraged. Yet, because of the novel nature of the current study and the specific hypotheses predicting patterns of sustained attention between high and low total ADHD symptom groups in a non-clinical population, further analyses of simple effects were conducted. The polynomial trend analyses revealed that the high ADHD group had an attenuation of response time towards the end of the repeated trials in relation to their earlier trial points. The low ADHD group had consistent response time throughout the repeated trials.

The results are consistent with the current study hypothesis and the literature in the clinical ADHD population. Dinn and colleagues (2001) commented that as the novelty of tasks dissipate over time, fading of sustained attention towards the end of a long series of test items would result in slowing of the reaction time at the end of the series, possibly because of the general under-arousal of the brain during the latter part of the task (Bradley & Golden, 2001). The findings from the current study confirmed that people with high self-reported ADHD symptoms without clinically significant ADHD had weaknesses in sustained attention similar to clinical ADHD samples using raw response times.

4.1.2. Hypothesis 2: Disinhibition and Impulsivity in relation to Hyperactivity/impulsivity symptoms

Inhibition was measured as completion time of the interference trial on the Stroop Color-Word task. The hypothesis that the hyperactive/impulsive symptom score would explain a significant proportion of the variance in the performance on the Stroop task was not supported. The Stroop task has been recognized as a measure of inhibition, a function mediated primarily by the frontal lobes. (Kimberg, D'Esposito, & Farah, 2000). Consistent with this description, the Stroop task has been identified as a sensitive measure for distinguishing between people with ADHD and people without ADHD (Sergeant, Geurts, & Oosterlann, 2002; Rapport, VanVoorhis, Tzelepis, & Friedman, 2001).

In the current study, the results did not replicate the findings in the clinical ADHD samples, however. That is, individuals who scored higher on measures of hyperactivity and impulsivity did not exhibit poorer performance on the Stroop tasks. There are several possible explanations for this null finding. It is possible that the task was not sufficiently sensitive to differentiate subtle differences in inhibition in a non-clinical sample, despite that fact that it has exhibited great efficacy in clinical samples. Alternatively, it is possible that there is no linear relationship between the magnitude of ADHD symptoms and the problems with inhibition in a non-clinical ADHD sample unless the severity of symptoms reaches a certain threshold (i.e., ADHD diagnosis).

The hypothesis that self-reported hyperactivity/impulsivity symptoms would be associated with a performance measure of impulsivity was supported: higher hyperactive/impulsive symptom scores were related to poorer performance on an impulsivity measure represented by accuracy on the Running Memory CPT test. As described earlier, the Running Memory task requires pressing either the right (a target is different from the previous stimulus) or the left mouse key (a target is the same as the previous stimulus). Although the task is easy, the participants have to remember these facts, and generate appropriate responses by pressing the correct button for each stimulus. In the current study, it was hypothesized that impulsive people would not be able to withhold their response until they have made a correct decision on whether to press the right or the left mouse key based on the stimulus on the screen: withhold response until the information processing is complete. The wrong responses would result in lowered accuracy scores. In fact, current findings indicate that people with more hyperactive/impulsive symptoms of ADHD perform more poorly on the Running Memory test. These findings suggest that the Running Memory test may provide an alternative means of measuring impulsivity in a non-clinical sample.

This result is consistent with findings in the clinical ADHD literature reporting differences between clinical and non-clinical samples. The CPT is claimed to be one of the most solid tests, and sometimes the only test, for demonstrating performance deficits in ADHD adults compared to normal adults (Epstein et al, 2001). In the current study, even among adults without ADHD, it is demonstrated that the Running Memory performance was differentially affected in relation to a different degree and severity of hyperactive/impulsive symptoms.

One important point was raised while comparing the bivariate correlational analyses and the multivariate hierarchical regressions. Bivariate correlational analyses revealed non-significant associations between ADHD measures with neuropsychological parameters, whereas multivariate hierarchical regression analyses resulted in significant associations between these two domains. Specifically, the bivariate correlation analyses, hyperactive/impulsive symptoms were not significantly correlated with the Running Memory accuracy. However, in the regression model, a significant relationship was found after adjusting for other controlling factors (i.e., site, gender, age, and education) (see Table 4 and Table 8). These findings suggest that the controlling factors in the current study had a "suppressor" effect. Therefore, future studies need to adjust for factors such as age, gender, and education because such adjustments are required to adequately document the associations between ADHD symptomatology with neurocognitive function.

4.1.3. Hypothesis 3: Working Memory in relation to Inattentive symptoms

Verbal working memory deficits have been frequently reported in clinical ADHD samples. Tests of working memory include backward span trial of the *WAIS-III* Digit Span task (Barkley et al., 1996; Holdnack et al., 1995; Kovner et al., 1998) and the Letter Number sequencing subtest of the WAIS-III. In the current study, the relationship between self-reported symptoms of inattention and Digit Span backward performance existed only as a trend. Because of this trend, additional analyses were conducted to examine the independent contributions of childhood versus current reported inattention symptoms.

When the total inattentive symptom score was separated into the childhood and current inattentive symptom scores, the childhood inattentive symptom score was a significant predictor of the Digit Span backward task performance. In fact, correlational analyses revealed that the correlation between childhood and current symptoms was relatively small (r values ranging from .428 to .6) compared to the correlations between subscales and the total ADHD scores (r values ranging from .826 to .954) (see Table 4 and 4a-c). The data suggest that the childhood symptoms may be the better predictor of the current working memory performance in neurocognitive measures.

There are several possible explanations for the finding that child symptom scores were better predictors of digit span performance than adult symptoms scores. First, it is possible that non-clinical adults are more reluctant to report current problems with attention, but feel comfortable reporting that such symptoms existed in childhood. This may be especially true for a group like the military where attention problems have different implications.

Second, it is possible that the organizational structuring of day-to-day activities within the military environment may compensate for relative performance weaknesses that would be otherwise related to symptoms of inattention. Therefore, participants in the current study may not have experienced the difficulties related to ADHD symptoms. It has been reported that environments having a strong external structure substitute compensates for weaknesses in prefrontal functioning, which helps people with ADHD to minimize the burden of the disorder related to its major executive functioning difficulties (i.e., organization, concept formation, problem solving, planning, and cognitive flexibility) (Faraone, Biederman, &Spencer et al., 2000; Spreen, & Strauss, 1998).

Third, adults may have learned and used compensatory behaviors for attention and executive functioning weaknesses that may have been present during childhood (Rapport et al., 2001). Therefore, symptoms may have been underreported (Murphy & Barkley, 1996a). This hypothesis is consistent with the conclusions reached by Faraone, Biederman, Feighner, and Monuteaux (2000) stating that the ADHD symptoms meeting diagnostic criteria in childhood are not as sensitive for adults. Alternatively, it is possible that childhood symptoms are a better measure of ADHD in relation to current cognitive problems in adults.

The relationship between inattentive symptoms and another verbal working memory was evaluated using the *WAIS-III,* Letter-Number sequencing task, and results with this measure did not support the hypothesis. One contribution to the null finding may be related to the phenomenon of “chunking.” Chunking involves a hierarchical organization of information that categorizes that information into separate units (Horton & Turnage, 1976). For instance, in the letter-number sequencing task, the letters and the numbers can be grouped and remembered separately with seven plus or minus two (7 $^{+}$/-2) bits of information capacity for each category (Miller, 1956). Therefore, we had expected the range for this task to be two to eight items in length (mixed letters and numbers). However, with the individuals’ capacity for chunking items into letters versus numbers categories within this task, the task with maximum difficulty turned out to be only four items long (letter and number sequences each). This task may not have been as heavily taxing on working memory as initially expected, and it also tapped into a slightly different cognitive component from working memory.

It should be also noted that the Letter-Number sequencing task was employed in the current study based on the theoretical grounds of defining working memory, although it has not been used in the ADHD literature extensively. Consistent with this theory, in the current study the Letter-Number sequencing had the highest correlation with the Digit Span backward ($r = .640$, $p < .01$), the most well known and utilized working memory measures. However, the relationship between Letter Number sequencing and the inattentive symptoms was not significant, possibly for the reason included above.

The hypothesis predicting a relationship between inattention and visual working memory was not supported. The computerized visual working memory Match to Sample accuracy score demonstrated a pronounced range restriction associated with a clear ceiling effect. For the entire sample, the accuracy score ranged from 80 percent to 100 percent, with 48.2 percent of the participants (27 out of 56 people) producing perfect accuracy on the task. Additionally, 80 percent accuracy represented missing only 3 trials of 15 total trials in this task.

One of the possible reasons for such limited variability and overall high accuracy comes from the way the Match to Sample task was created. The task was originally developed for studying working memory in monkeys (Jacobson, 1935; Diamond, 1990). Specifically, these studies demonstrated delayed match to sample performance decrements in monkeys with dorsolateral prefrontal lobe damage. However, this task may have been too simplistic as a working memory measure for a normal functioning sample of non-clinical adults: the time delay was too short and/or the form was too easy to remember and match.

Additionally, related to the above issue and based on Baddeley's working memory model (1986), the Match to Sample task assesses the visuospatial sketchpad component of passive working memory, which is one of the slave systems. Most findings with ADHD, however, have examined the central executive component of working memory, and not the passive slave components of the phonological loop and visuospatial sketchpad. That is, although the studies have revealed that the working memory deficits are evident among ADHD samples, the most affected component of working memory may be the central executive aspects of functioning. Thus, this visual working memory task may not tap into the same neural systems associated with symptoms of ADHD.

Another explanation of the null finding in the Match to Sample task in relation to visual working memory task is the nature of the computerized tasks. Computerized tasks are sensitive to changes in the performance. Traditional neuropsychological tests, on the other hand, are more beneficial in establishing baseline performance. Thus, a traditional neuropsychological method of assessing working memory could have been more useful in assessing visual working memory in the current study.

4.2. General Discussion

The goal of the current study was to examine the extent to which the relationship between the reported symptoms of ADHD and the cognitive weaknesses hold true for a non-clinical adult sample using the neurocognitive assessment measures. In this study, some of the hypotheses regarding this relationship were supported but others were not. Although the absence of consistent support for this relationship suggests that self-reported symptoms of ADHD cannot reliably predict performance on neurocognitive tasks, several limitations of the current study preclude ruling out the relationship. For example, it is possible that the neuropsychological measures that were used in the current study were not sensitive enough to detect attentional weaknesses in a non-clinical sample. These measures were chosen because of the usefulness in detecting differences between clinical ADHD samples and non-clinical samples. The differences within the sample may have been too subtle for these measures to grasp, or in other words, many of the test paradigms were too simple and insensitive for use with normal samples (e.g., Stroop, Match to Sample).

Another issue limiting the current study may be that many traditional neuropsychological tools do not measure one clear construct. Traditional neuropsychological assessment techniques assess many dimensions of frontal lobe functioning, and may therefore lack discriminatory value in terms of differentiating different disorders (Alexander & Stuss, 2000). This criticism may apply to the current study, which perhaps was not able to tap into the specific cognitive functions that were under investigation. For instance, the Letter Number sequencing task is used as a working memory measure but at the same time the task examines the chunking capacity. Therefore, it is hard to distinguish how much of the working memory capacity and how much of the chunking capacity were reflected in the Letter Number task.

Another example related to the lack of clear discriminatory qualities of neuropsychological measures is the frequent use of the same measure for different purposes. In the present study, the various neuropsychological tasks were significantly inter-related (see Table 4). Overlap in content validity of the various measures remains as one of the controversial areas in the field of neuropsychology. For example, in the current study the Running Memory task was used to assess impulsivity as well as sustained attention. However, as an impulsivity measure, the accuracy score of the Running Memory task was used to reflect the commission errors, which are purported to be the result of impulsive responding. Likewise, the response time scores of Running Memory were used to reflect the sustained attention over a long period of time. Therefore, although one task was used to measure two different constructs, specific scores were used to target unique component of each measure.

Disinhibition, impulsivity, and working memory difficulties are predominant problems reported with sub-types of ADHD, but the overarching difficulties that people with high ADHD symptoms encounter are executive function deficits which include all of these features (Barkley, 1997). Barkley asserted that there exists a high correlation between inhibition, working memory, and sustained attention because the inhibition component is required for successful performance on both working memory and sustained attention tasks. Therefore, inhibition, working memory, and sustained attention are all linked together. For instance, Fuster (1989, 1995) stated that the proficiency of working memory is dependent on response inhibition and interference control. Therefore, the neurocognitive weaknesses as they relate to attentional features are far more complicated than was initially characterized by the current study analyses.

In the adult ADHD literature, it has been documented that ADHD adults may out-grow or learn compensatory behaviors for cognitive difficulties that were present during childhood (Rapport et al., 2001). Because the participants in the current study, as a whole, were normal to high functioning people, they could have experienced attentional difficulties in the past for which they have since developed compensatory behavior that they now utilize when encountering difficulties. Although it was not fully evident in the neurocognitive test results, this compensatory behavior may be more evident if functional brain imaging techniques were employed. Although there were no differences in terms of the end point of performance on most of these tasks, the process of achieving the result may vary for individuals who have developed compensatory behaviors. That is, the use of functional imaging technology could objectively demonstrate recruitment of other brain region for the same work necessary. For instance, positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) would allow examination of activities (e.g., blood flow, oxygen consumption, and glucose uptake) in specific regions and additional regions of the brain while performing a task (Feinberg & Farah, 2003). Only further study employing functional brain imaging techniques would be able to answer this question.

In the studies of clinical ADHD and cognitive weaknesses, a variety of studies reported different cognitive weaknesses using different measures. Similarly in the current study, consistent with the heterogeneous symptom presentation of ADHD in a clinical sample, the non-clinical sample also had heterogeneity in the cognitive performance tasks associated with the specific constructs. For instance, some of the measures were significantly related to ADHD features in terms of cognitive weaknesses (e.g., Digit Span backward-verbal working memory), whereas other measures of the same constructs were not (e.g., the Match to Sample-visual working memory). Features of ADHD symptoms can be divided into three predominant subtypes existing on a continuum. In the current study, different groups were formed based on the predominant symptoms of ADHD to reduce heterogeneity of symptoms within each group. However, these factors combined with naturally occurring intra-individual variability in performances (strengths and weaknesses), may have complicated interpretation of the findings. Measuring cognitive performance is a complicated process requiring integration of many different factors to develop models of neurocognitive functioning.

4.3. Limitations

Some of the limitations of the current study include: (1) insensitivity of some of the neurocognitive measures that were chosen; (2) lack of control of possible confounding factors; and (3) limited generalizability of the study. As discussed earlier in detail, the insensitivity issue of the chosen measures was one of the possible limitations. For instance, visual working memory measures that can employ longer time delays and more complicated figures with a greater number of options to choose a matching target from may be more appropriate in examining non-clinical samples. Although most of the neurocognitive tests were chosen for their efficacy in distinguishing people with ADHD and without ADHD, it was not as effective for detecting subtle differences in non-clinical adults. More complicated paradigm of these measures may be able to address this issue.

Several factors that were not addressed may have influenced performances on the tests independent of ADHD measures. For instance, fatigue and lack of sleep are frequently documented as factors adversely affecting cognitive task performances (Matthews, Davies, Westerman, & Stammers, 2000). Especially the measure of vigilance that requires sustained attention is reported to be significantly affected by sleep deprivation (Krueger, 1989). Unfortunately, because the current study used existing data from a larger study, documentation of the fatigue aspects of the participants' performance on this task had not been incorporated into the available data when it was adapted into a non-traceable form for use in this study. Furthermore, the sleep status of participants was not documented at any part. Fatigue and sleep contributions could not be factored into the data analyses. It is a limitation pertinent to the current study and inherent to studies that utilize data from existing studies.

Another issue involving the current study is limited generalizability. The participants were of both genders, all ethnicities, and ages between 18 and 49. However, because the study was conducted at military sites, the majority of participants were uniformed services men and women who represent a specific population. Furthermore, for the purpose of the larger study, individuals were screened for any chronic physical and psychological illnesses that may exclude them from deployment (e.g., history of psychiatric disorders, medical diagnosis with diabetes, coronary artery diseases). Overall health was better for the sample that was used in the current study than may be true for the general civilian population. Additionally, 46.7% of the total participants had more than 16 years of education (see Table 1). Therefore, occupation, and the superior health status and level of education may limit the extrapolation of the findings to the general population.

4.4. Implications

Some of the cognitive weaknesses reported in the clinical ADHD samples were replicated in the results of the current study using a non-clinical sample in relation to the self-reported ADHD symptoms. People with increased number and greater severity of ADHD symptoms had greater *cognitive weaknesses* in some tasks. The attentional symptoms and related difficulties may exist along a continuum, and it is possible that people with increased self-reported symptoms of ADHD also may have the *behavioral difficulties* that are similar to that of a clinical ADHD population.

ADHD afflicted adults suffer consequences in personal and professional life. For instance, compared to adults without ADHD, those with ADHD have more interpersonal and social problems (unstable marriages), unsatisfactory work histories (obtaining and maintaining a job), more car accidents, and low academic achievement (Barkley et al., 1996; Murphy & Barkley, 1996a; Hinshaw, 1992). Specifically related to the disruption of dorsolateral prefrontal cortex in inattentive type ADHD, working memory difficulties are accompanied by various learning disabilities (Cummings, 1993). Further, Seidman and colleagues (1998) reported that people with ADHD have a history of failure in academic settings and at work even without learning disability or psychiatric comorbidity. In a normal population, the disruption in their functioning may be minimal, yet, this may still have an effect on afflicted individuals.

It is conceivable that people at the high end of the continuum may experience similar difficulties in their personal and professional life, and further, these people could actually benefit from treatment measures that were created for the clinical ADHD population. It has been reported that when people with ADHD were identified and treated, the individuals experienced not only symptom reduction, but also improved work and/or academic performance (Pary et al., 2002). However, because a clinical diagnosis cannot be made for this particular sample (on the high end of the continuum, but not meeting DSM-IV criteria), pharmacological prescriptions would not be available for them. Therefore, utilizing cognitive behavioral intervention methods, teaching people to structure or organize their work and surroundings may help to improve the performance at work, home, and school. In fact, there is evidence that people with ADHD, when provided structure, can perform better than they can without structure (Faraone, Biederman, Spencer, et al., 2000), and the people at the high end of the spectrum may also benefit from these interventions.

Similarly, there are reports on a high prevalence of maladaptive health behaviors among ADHD samples. In a study of adults with diagnosed ADHD, alcohol abuse and dependence were identified in 34% of the sample, and drug abuse in 30% (Shekim, Asarnow, Hess, Zaucha, & Wheeler, 1990). Parallel to the findings in the clinical sample, these unhealthy behaviors may be more prevalent among people who are in the non-clinical category but nonetheless endorse high ADHD symptoms. These maladaptive health behaviors among non-clinical samples can be examined and treated in a similar manner as for clinical ADHD groups.

Although the current study focused on cognitive difficulties that were associated with ADHD symptoms, there are adaptive features of ADHD symptoms. People with ADHD are more suitable for jobs or an environment where change is constant and lots of novel situations are presented. For some, the change and the novelty of work may arouse anxiety, but people with ADHD features (but not with severe ADHD which can cripple normal functioning) may be able to excel in the fast changing environment (Ratey & Johnson, 1997). It is because the novelty of tasks and the change of tasks may stimulate the under-aroused prefrontal region (hypofrontality), and the people with ADHD can function better than others without the features of ADHD. The different aspects of ADHD, which are positive, should not be ignored, particularly when investigating a normal to high functioning group of people.

4.5. Future directions

While the current study addressed questions regarding features of ADHD and cognitive weaknesses in a non-clinical adult sample, more questions still need to be answered. From the current study, it became obvious that some of the measures that were used may not have been sensitive enough to measure subtle differences in the non-clinical population. Studies that use more sensitive and possibly more complicated measures should be able to better delineate the relationship between cognitive weaknesses and ADHD symptoms along a continuum.

Another interesting question that emerged from the current investigation is whether the people who are high on the symptom scale without ADHD would actually have more maladaptive health behaviors and report low quality of life as seen in the clinical ADHD sample. If the higher prevalence of such report exists, then the outcome studies that utilize behavioral modifications interventions that are developed to help people with ADHD can be conducted. The current study measured possible cognitive difficulties, but examining behavioral consequences from these cognitive difficulties and the efficacy of behavioral modification methods would allow us to understand the features of ADHD more completely.

Finally, although the current study focused on the negative aspects of ADHD, according to an evolutionary perspective of ADHD (Ratey & Johnson, 1997), there may be positive and adaptive features of ADHD (e.g., being adventurous, being able to perform better in a situation that is changing quickly). Investigating cognitive and behavioral strengths associated with ADHD features may add strength to our knowledge of the attentional features.

Attention is one of the most important aspects of human cognition with substantial effects on perception, learning, memory and appropriate control of behavior. Further deficits in attention are likely to negatively affect behavior and performance as is evident in individuals who suffer from ADHD. Given the important role of attention in cognition and performance, it seems valuable to understand how to measure attention and how attentional weakness may affect performance, even in a non-clinical population. Further investigating all aspects of attention (e.g., cognitive and behavioral, and adaptive and maladaptive) in non-clinical ADHD samples would help to understand how one aspect of human cognition affects the entire domains of cognitions and behaviors.

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Appendix A: Notice of Project Approval

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
F. EDWARD HEBERT SCHOOL OF MEDICINE
4301 JONES BRIDGE ROAD
BETHESDA, MARYLAND 20814-4799

Notice of Project Approval
Original

Protocol Information:

Project Number:	**T072GJ-01**
Principal Investigator:	**Su Jong Kim**
Department:	MPS - Medical and Clinical Psychology
Sponsor:	Uniformed Services University of the Health Sciences
Project Type:	USUHS - Dissertation Awards
Title:	**Neuropsychological Features of ADHD Symptos Among Normal Adults**
Project Period:	01/06/2004 - 06/30/2004
Activity Period:	01/06/2004 - 06/30/2004

Assurance and Progress Report Information:

Name	Sup.	Approval Type	Status	Approved On	Due Date	Forms Rcvd
	0					
IRB	0	Exempt	Approved	01/06/2004	N/A	N/A
Progress Rpt	0	Final	To be submitted		03/01/2004	N/A

Remarks:

This Notice of Project Approval represents the Office of Research has reviewed and approved your project.
Please Note: Upon completion of your project a Final Progress Report (USU Form 3210) must be submitted to the Office of Research.

I have reviewed the project described above and approve the research for this project. However, this action does not imply that the appropriate assurances have been obtained nor should work begin on this project until all appropriate assurances are obtained. No funding is provided for this activity period.

Questions regarding this award should be directed to Sheila J. Dudley at 301-295-9818 in the Office of Research.

Steve Kaminsky

Steven G. Kaminsky, Ph.D.
Vice President for Research
Uniformed Services University of the Health Sciences

cc: David S. Krantz
File

Appendix B: Murphy & Barkley's ADHD questionnaire

Current Symptom Scale- Self-Report Form

Instruction: Please circle the number next to each item that best describes your behavior *during the past 6 months.*

Items:	Never or rarely	Some-times	Often	Very often
1. Fail to give close attention to details or make careless mistakes in my work	0	1	2	3
2. Fidget with hands or feet or squirm in seat	0	1	2	3
3. Have difficulty sustaining my attention in tasks or fun activity	0	1	2	3
4. Leave my seat in situations in which seating is expected	0	1	2	3
5. Don't listen when spoken to directly	0	1	2	3
6. Feel restless				
7. Don't follow through on instructions and fail to finish work	0	1	2	3
8. Have difficulty engaging in leisure activities or doing fun things quietly	0	1	2	3
9. Have difficulty organizing tasks and activities	0	1	2	3
10. Feel "on the go" or "driven by a motor"	0	1	2	3
11. Avoid, dislike, or am reluctant to engage in work that required sustained mental effort	0	1	2	3
12. Talk excessively	0	1	2	3
13. Lose things necessary for tasks or activities	0	1	2	3
14. Blurt out answers before questions have been completed	0	1	2	3
15. Am easily distracted	0	1	2	3
16. Have difficulty awaiting turn	0	1	2	3
17. Am forgetful in daily activities	0	1	2	3
18. Interrupt or intrude on others	0	1	2	3

Childhood Symptom Scale- Self-Report Form

Instruction: Please circle the number next to each item that best describes your behavior *when you were a child age 5 to 12 years.*

Items:	Never or rarely	Some-times	Often	Very often
1. Failed to give close attention to details or made careless mistakes in my work	0	1	2	3
2. Fidgeted with hands or feet or squirmed in seat	0	1	2	3
3. Had difficulty sustaining my attention in tasks or fun activity	0	1	2	3
4. Left my seat in classroom or in other situations in which seating was expected	0	1	2	3
5. Didn't listen when spoken to directly	0	1	2	3
6. Felt restless				
7. Didn't follow through on instructions and failed to finish work	0	1	2	3
8. Had difficulty engaging in leisure activities or doing fun things quietly	0	1	2	3
9. Had difficulty organizing tasks and activities	0	1	2	3
10. Felt "on the go" or "driven by a motor"	0	1	2	3
11. Avoided, disliked, or was reluctant to engage in work that required sustained mental effort	0	1	2	3
12. Talked excessively	0	1	2	3
13. Lost things necessary for tasks or activities	0	1	2	3
14. Blurted out answers before questions were completed	0	1	2	3
15. Was easily distracted	0	1	2	3
16. Had difficulty awaiting turn	0	1	2	3
17. Was forgetful in daily activities	0	1	2	3
18. Interrupted or intruded on others	0	1	2	3

Appendix C: Tables

Table 1

Subject Demographics

Variable		Total (n=75)	%
Gender			
	Male	50	66.7
	Female	25	33.3
Ethnicity			
	White/Caucasian	51	68.0
	African/African-American	8	10.7
	Hispanic	6	8.0
	Asian/Asian American	4	5.3
	Pacific Islander	4	5.3
	Other	2	2.7
Years of Education			
	= 12 (High School)	13	17.3
	> 12, < 16 (Some college)	21	28.0
	= 16 (College Graduate)	6	8.0
	> 16 (Post-graduate)	35	46.7

Table 2

Mean Scores (and Standard Deviations), Minimum and Maximum scores for Hyperactive Symptom Scores, Inattentive Symptoms Scores, and Total ADHD Symptom Scores

N=75	Mean (SD)	Minimum	Maximum
Hyperactive	8.52 (6.92)	0	27
Inattentive	6.45 (5.67)	0	21
Total ADHD	14.97 (11.87)	0	46

Table 3

Distribution of Measures from the Neuropsychological Dependent Variables of all Participants

Test	Traditional Neuropsychological Tasks				Computerized Tasks		
	CWtime	DSFcons	DSBraw	LNraw	RMaccu	RMsd	MTSaccu
Total n	73	74	75	75	48	48	56
Mean	106.64	6.41	8.40	12.63	88.02	130.04	94.88
SD	22.97	1.29	2.48	2.59	6.56	20.86	5.961
Min	64	4	3	9	74.68	81.59	80.00
Max	165	9	13	19	100.00	176.86	100.00

Note: CWtime=Stroop Color-Word completion time; DSFcons= Digit Span Forward consistency score; DSBraw=Digit Span Backward raw score; LNraw=Letter-Number Sequencing raw score; RMaccu= Running Memory accuracy score; RMsd= Running Memory response time standard deviation score; MTSaccu= Match to Sample accuracy

Table 4

Bivariate Correlational Analyses of Variables with Inattentive and Hyperactive ADHD Symptoms

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Inattentive	-										
N											
2. Hyperactive	.776**	-									
N	75										
3. Total ADHD	.930**	.954**	-								
N	75	75									
4. Education	-.054	-.106	-.088	-							
N	75	75	75								
5. DSF cons	-.018	-.041	-.032	.446**	-						
N	74	74	74	74							
6. DSB raw	-.198	-.153	-.184	.323**	.555**	-					
N	75	75	75	75	74						
7. LN raw	-.042	-.108	-.083	.411**	.566**	.640**	-				
N	75	75	75	75	74	75					
8. CW time	-.066	-.082	-.079	-.277*	-.259*	-.114	-.165	-			
N	73	73	73	73	72	73	73				
9. RM accuracy	-.071	-.231	-.171	.363*	.253	.289*	.290*	-.450**	-		
N	48	48	48	48	48	48	48	47			
10.RM sd	-.104	-.010	-.040	-.445**	-.200	-.191	-.262*	.350*	-.329*	-	
N	48	48	48	48	48	48	48	47	48		
11.MTS accuracy	-.124	-.113	-.125	-.043	.189	.143	.086	-.145	.354*	-.261	-
N	56	56	56	56	55	56	56	55	48	48	

Note. Inattentive= total inattentive symptom score, Hyperactive= total hyperactive/impulsive symptom score, Total ADHD=total scores on ADHD questionnaire, DSFcons= Digit Span forward consistency score, DSBraw=Digit Span backward raw score, LN raw=Letter Number sequencing raw score, CW time=Stroop Color Word time, RM accuracy= Running Memory accuracy, RM sd= Running Memory response time standard deviation, and MTS accuracy=Match to Sample accuracy.

*p<.05, **p<.01

Table 4a

Bivariate Correlational Analyses of Variables with Childhood and Current ADHD Symptoms

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Childhood ADHD	-										
N											
2. Current ADHD	.551**	-									
N	75										
3. Total ADHD	.926**	.826**	-								
N	75	75									
4. Education	-.202	.107	-.088	-							
N	75	75	75								
5. DSF cons	-.094	.070	-.032	.446**	-						
N	74	74	74	74							
6. DSB raw	-.286*	.021	-.184	.323**	.555**	-					
N	75	75	75	75	74						
7. LN raw	-.153	.044	-.083	.411**	.566**	.640**	-				
N	75	75	75	75	74	75					
8. CW time	-.031	-.130	-.079	-.277*	-.259*	-.114	-.165	-			
N	73	73	73	73	72	73	73				
9. RM accuracy	-.314*	.075	-.171	.363*	.253	.289*	.290*	-.450**	-		
N	48	48	48	48	48	48	48	47			
10.RM sd	.087	-.206	-.040	-.445**	-.200	-.191	-.262*	.350*	-.329*	-	
N	48	48	48	48	48	48	48	47	48		
11.MTS accuracy	-.119	-.093	-.125	-.043	.189	.143	.086	-.145	.354*	-.261	-
N	56	56	56	56	55	56	56	55	48	48	

Note. Childhood ADHD= total childhood symptom score, Current ADHD= total current symptom score, Total ADHD=total scores on ADHD questionnaire, DSFcons= Digit Span forward consistency score, DSBraw=Digit Span backward raw score, LN raw=Letter Number sequencing raw score, CW time=Stroop Color Word time, RM accuracy= Running Memory accuracy, RM sd= Running Memory response time standard deviation, and MTS accuracy=Match to Sample accuracy.

*p<.05, **p<.01

Table 4b

Bivariate Correlational Analyses of Variables with Childhood and Current Inattentive ADHD Symptoms

Variable	1	2	3	4	5	6	7	8	9	10
1. Childhood Inatt	-									
N										
2. Current Inatt	.428**	-								
N	75									
3. Education	-.186	.139	-							
N	75	75								
4. DSF cons	-.121	.126	-.446**	-						
N	74	74	74							
5. DSB raw	-.335**	.053	.323**	.555**	-					
N	75	75	75	74						
6. LN raw	-.151	.117	.411**	.566**	.640**	-				
N	75	75	75	74	75					
7. CW time	-.003	-.127	-.277*	-.259*	-.114	-.165	-			
N	73	73	73	72	73	73				
8. RM accuracy	-.293*	.195	.363*	.253	.289*	.290*	-.450**	-		
N	48	48	48	48	48	48	47			
9.RM sd	.072	-.259	-.445**	-.200	-.191	-.292*	.350*	-.329*	-	
N	48	48	48	48	48	48	47	48		
10.MTS accuracy	-.149	-.043	-.043	.189	.143	.086	-.145	.354*	-.261	-
N	56	56	56	55	56	56	55	48	48	

Note. Childhood Inatt= childhood inattentive symptom score, Current Inatt= current inattentive symptom score, DSFcons= Digit Span forward consistency score, DSBraw=Digit Span backward raw score, LN raw=Letter Number sequencing raw score, CW time=Stroop Color Word time, RM accuracy= Running Memory accuracy, RM sd= Running Memory response time standard deviation, and MTS accuracy=Match to Sample accuracy.

*p<.05, **p<.01

Table 4c

Bivariate Correlational Analyses of Variables with Childhood and Current Hyperactive ADHD Symptoms

Variable	1	2	3	4	5	6	7	8	9	10
1. Childhood Hyp	-									
N										
2. Current Hyp	.600**	-								
N	75									
3. Education	-.187	.064	-							
N	75	75								
4. DSF cons	-.060	.005	-.446**	-						
N	74	74	74							
5. DSB raw	-.209	-.014	.323**	.555**	-					
N	75	75	75	74						
6. LN raw	-.133	-.036	.411**	.566**	.640**	-				
N	75	75	75	74	75					
7. CW time	-.049	-.118	-.277*	-.259*	-.114	-.165	-			
N	73	73	73	72	73	73				
8. RM accuracy	-.295*	-.061	.363*	.253	.289*	.290*	-.450**	-		
N	48	48	48	48	48	48	47			
9.RM sd	.087	-.126	-.445**	-.200	-.191	-.292*	.350*	-.329*	-	
N	48	48	48	48	48	48	47	48		
10.MTS accuracy	-.081	-.136	-.043	.189	.143	.086	-.145	.354*	-.261	-
N	56	56	56	55	56	56	55	48	48	

Note. Childhood Hyp= childhood hyperactivity symptom score, Current Hyp= current hyperactivity symptom score, DSFcons= Digit Span forward consistency score, DSBraw=Digit Span backward raw score, LN raw=Letter Number sequencing raw score, CW time=Stroop Color Word time, RM accuracy= Running Memory accuracy, RM sd= Running Memory response time standard deviation, and MTS accuracy=Match to Sample accuracy.

*p<.05, **p<.01

Table 5

Three Block Hierarchical Linear Regression Model of Digit Span Forward Consistency with Combined Total Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=74							
Block 1 -control variables	.023	-.019	.023				
Site				-.194	-.673	.367	-.248
Gender				.082	.233	.298	.085
Age				-.050	-.012	.026	-.054
Block 2 – education	.239***	.195***	.217***				
Years of education				.466	.300	.068	.595***
Block 3 –ADHD	.241**	.185**	.002				
Combined Scores				.041	.004	.012	.044

*p< .05. **p< .01. ***p< .001

Table 6

Three Block Hierarchical Linear Regression Model of Running Memory Choice Reaction time variability with Combined Total Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=48							
Block 1 -control variables	.064	.000	.064				
Site				.024	1.465	8.553	.033
Gender				-.038	-1.706	6.259	-.039
Age				.022	.104	.664	.024
Block 2 – education	.200*	.126*	.136*				
Years of education				-.368	-3.729	1.399	-.467*
Block 3 –ADHD	.201	.105	.000				
Combined Scores				-.010	-.0193	.261	-.011

*p<.05.

Table 7

Three Block Hierarchical Linear Regression Model of Stroop Color-Word Performance with Hyperactive/impulsive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=73							
Block 1 -control variables	.118*	.080*	.118*				
Site				-.134	-8.706	7.342	-.181
Gender				.086	4.258	5.607	.089
Age				.116	.520	.506	.129
Block 2 – education	.141*	.090*	.022				
Years of education				-.153	-1.800	1.333	-.202
Block 3 –ADHD	.142	.078	.001				
Hyperactive Scores				-.032	-.117	.413	-.035

sr= semi-partial correlations (sr2= proportion of variance that is uniquely accounted for by each predictor); B=regression coefficient; SEB=standard error of coefficient; β=standardized regression coefficient
*p< .05

Table 8

Three Block Hierarchical Linear Regression Model of the Running Memory Accuracy with Hyperactive/impulsive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=48							
Block 1 -control variables	.212*	.159*	.212*				
Site				.121	2.348	2.387	.170
Gender				-.183	-2.611	1.749	-.190
Age				-.251	-.383	.187	-.284*
Block 2 – education	.283**	.216**	.070*				
Years of education				.212	-.679	.394	.271
Block 3 –ADHD	.369***	.294***	.087*				
Hyperactive Scores				-.295	-.294	.122	-.325*

*p< .05. **p<.01. ***p<.001

Table 9

Three Block Hierarchical Linear Regression Model of Digit Span Backward Performance with Inattentive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=75							
Block 1 -control variables	.036	-.005	.036				
Site				.003	.019	.730	.004
Gender				.086	.460	.594	.088
Age				-.112	-.053	.053	-.122
Block 2 – education	.114	.063	.078*				
Years of education				.260	.318	.135	.331*
Block 3 –ADHD	.156*	.095*	.043				
Inattentive Scores				-.206	-.094	.050	-.214

*p< .05

Table 10

Three Block Hierarchical Linear Regression Model of Digit Span Backward Raw Score with Childhood Inattentive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=75							
Block 1 -control variables	.036	-.005	.036				
Site				.000	-.003	.706	-.001
Gender				.116	.630	.582	.120
Age				-.102	-.048	.051	-.110
Block 2 – education	.114	.063	.078*				
Years of education				.220	.273	.133	.284*
Block 3 –Childhood ADHD	.205**	.148**	.092**				
Inattentive Symptom Score				-.303	-.206	.073	-.317**

*p< .05. **p<.01

Table 11

Three Block Hierarchical Linear Regression Model of Letter-Number Sequencing Performance with Inattentive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=75							
Block 1 -control variables	.105*	.067*	.105*				
Site				.091	.629	.746	.117
Gender				.053	.295	.607	.054
Age				-.059	-.029	.054	-.064
Block 2 – education	.186**	.139**	.081**				
Years of education				.279	.356	.138	.356*
Block 3 –ADHD	.189*	.130*	.003				
Inattentive Scores				-.052	-.025	.051	-.054

*p< .05. **p< .01

Table 12

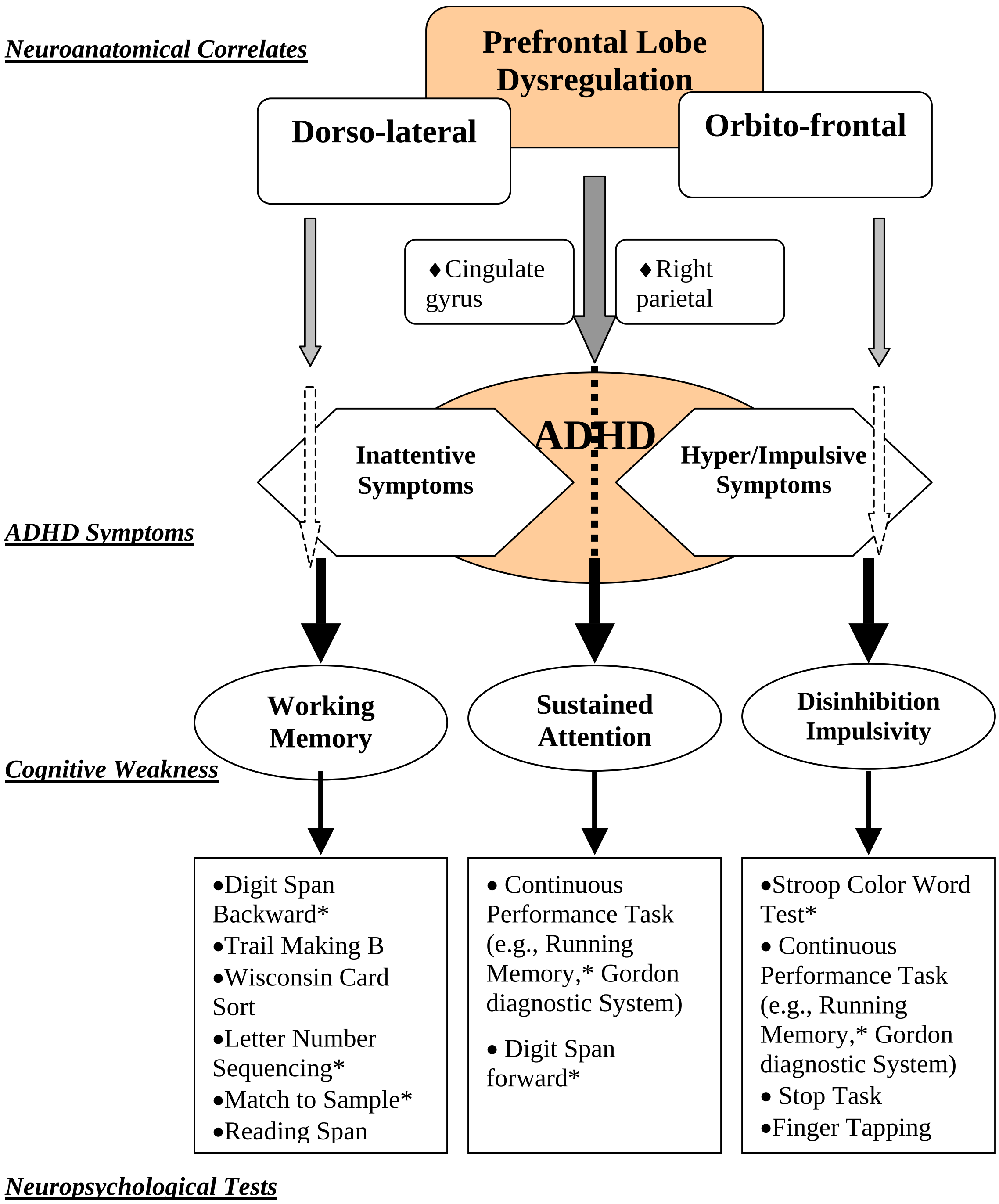
Three Block Hierarchical Linear Regression Model of Match to Sample Performance with Inattentive Symptom Score

Model and variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SEB	β
n=56							
Block 1 -control variables	.098	.046	.098				
Site				-.107	-1.780	2.211	-.148
Gender				-.108	-1.389	1.714	-.113
Age				-.276	-.370	.178	-.318*
Block 2 – education	.104	.034	.006				
Years of education				.075	.227	.404	.099
Block 3 –ADHD	.118	.030	.014				
Inattentive Scores				-.119	-.130	.145	-.127

*p< .05

Appendix D: Figures

Figure 1: Model of ADHD in Relation to Neuroanatomical Correlates, Cognitive Functions, and Neuropsychological Measures



Note: * Measures used in the current study

Figure 2: Choice Reaction Time Trend in Low ADHD Symptom Group

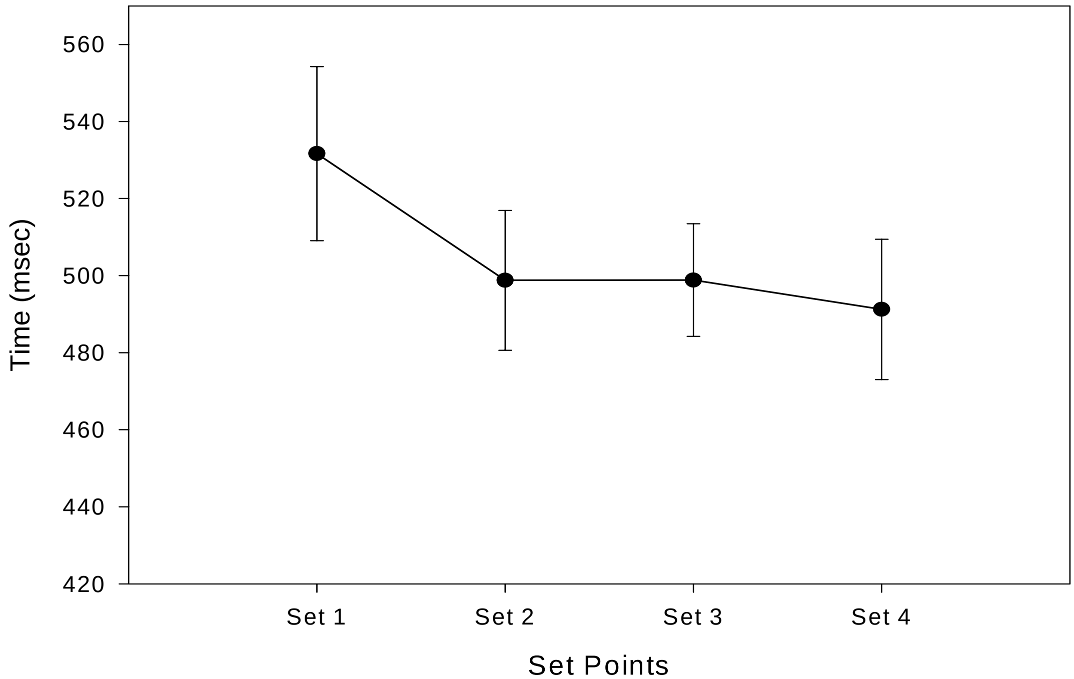


Figure 3: Choice Reaction Time Trend in High ADHD Symptom Group